AIRBORNE BISTATIC RADAR

LIMITATIONS AND SAMPLE CALCULATIONS

THESIS

William P. Thomson
Captain, USAF

AFIT/GE/ENG/85D-49

DTIC
SELECTED
FEB 1 3 1986
A

DEPARTMENT OF THE AIR FORCE

AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

86   2 12   088

AIRBORNE BISTATIC RADAR

LIMITATIONS AND SAMPLE CALCULATIONS

THESIS

William P. Thomson
Captain, USAF

AFIT/GE/ENG/85D-49

AIRBORNE BISTATIC RADAR

LIMITATIONS AND CALCULATIONS

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Electrical Engineering

William P. Thomson, B.S.

Captain, USAF

December 1985

Acknowledgments

I am deeply indebted to Major John Reed, RADC/OCDE for his assistance in providing the background information necessary in this study. I am also indebted to my thesis advisor, Major Ken Casto, for his time and assistance in bringing this study to a successful conclusion. Finally, I wish to thank Marilyn Thomson for her unselfish assistance.

William P. Thomson

Table of Contents

List of Figures

Figure   Page

List of Tables

Abstract

This thesis examined the effects of system configuration and transmitted waveform as applied to an airborne bistatic radar. The study concentrates on the limiting effects of the transmitted signal parameters, the signal to clutter ratio, and the doppler spread of the receiver beam.

The analysis was performed by constructing a computer model to graphically display the results of the applicable equations. The equations developed in this study are: The power limited region equation, the isorange equation, the isodoppler equation, and the signal to clutter ratio. These equations and those of ellipsoidal geometry were used to develop the bistatic radar model.

AIRBORNE BISTATIC RADAR

LIMITATIONS AND SAMPLE CALCULATIONS

I.   Introduction to Bistatic Radar

Airborne Bistatic Radar

An Airborne Bistatic Radar System is an electro-magneti
detection device, composed of separate transmitter and
receiver platforms, used to find range and velocity charac-
teristics of objects by measuring time of flight and doppler
shift of the transmitted signal. The receiver is always
mounted on an airborne platform.

Assumptions

A basic assumption of this thesis requires that the
transmitter and receiver are synchronized in some fashion.
Further, it is assumed that the receiver processor has the
ability to detect the signal and do whatever processing is
required. These assumptions were set by the Tactical Sur-
veillance Division, Rome Air Development Center, Griffiss
AFB, NY. This thesis concentrates on the limiting effects
of the transmitted signal parameters, the signal to clutter
ratio, and the doppler spread of the receiver beam. The
signal detection and estimation problem as well as the syn-
chronization problem are under investigation by others.

The Problem

The airborne receiver platform motion is not constrained to any velocity or motion with respect to a transmitter. Therefore, the received signal is subject to the inherent characteristics resulting from bodies with independent motion; in particular, the doppler shift of any signal which would travel between the transmitter and the receiver, or between the transmitter, a target and the receiver platform. This thesis outlines the characteristics of a signal which limit the surveillance area of the receiver platform. A computer model has been developed to incorporate the concepts outlined in this study. The model (see Appendix A) provides an analysis tool for bistatic radar development.

Developments in the radar field have moved rapidly forward with the marriage of the digital computer to the radar detection arena. The terminology in a bistatic radar system is built upon a traditional base. However, new terminology must be introduced to explain the change in the problem and system configuration. The terminology, limitations and major components of the bistatic system are outlined in chapter II. The configuration of the platforms and characteristics of the transmitted waveform are discussed as well as some advantages of a bistatic system. A list of current research is also provided.

Analysis of the Problem

The defining parameters and equations are developed in chapter III. In particular, the range, geometry and system

performance equations are developed to demonstrate the system configuration as well as the ability of the system to perform.

Limiting Regions. The limiting regions of the bistatic radar are defined by two equations. The power and the isorange equations are developed to explain the viewing area of a bistatic radar and its unique blind zone. For example, there is a minimum and a maximum range associated with the isorange equation which is independent of the power equation.

Doppler Effects. The bistatic doppler equation is not the same as the monostatic radar doppler equation. The motion of the three objects (receiver, transmitter, and target) must be considered in their relative radial velocities with respect to each other. The doppler equation must also account for the secondary doppler shift (and relative change in wavelength) as the signal travels from the transmitter, strikes the target, and is reradiated to the receiver platform.

Signal to Clutter Ratio. The signal to clutter power ratio (SCR) is defined and parameters of interest are explained. The clutter cell area is defined and its affect on the SCR is shown. A surface cross section per unit area is modeled from previous work and incorporated into the model.

Finally the doppler spread of the clutter cell is developed. The equations for the doppler spread show that the bistatic system is dynamic and dependent upon the motion and beam shapes of the transmitter receiver pair.

3

Demonstration of the Model

The results of the analysis were put into an inter-active computer model which was exercised to demonstrate some of the features outlined in chapters II and III. Chapter IV contains the results of the simulation. The waveform limited regions are shown to be dependent upon the pulse repetition frequency (prf), the pulse width and the prf multiple. The effects of these variables are shown in graphical form. Doppler contour maps of the system are shown to explain the effects of the transmitter receiver target motion. The maps demonstrate the effects of the relative velocities of the transmitter and receiver on the ground plane.

Signal to clutter tables and graphs are provided. The effect of changes in target radar cross section on the SCR is demonstrated. The doppler spread of the receiver beam is also shown in graphical form. It is demonstrated by the graphs that the effects of the platform motion as well as the receiver look angles have predictable results. The doppler spread is shown to be a well behaved phenomenon. Finally, a sample air to air senario is provided to show the dynamic nature of the system.

Findings and Conclusions

A summary of the detection regions and the minimization or maximization of the detection regions is provided in chapter V. Several recommendations for follow on analysis are provided.

4

II.   Bistatic Radar

Background

The idea of a passive radar excites the imagination of the Air Force information gathering community. If it were possible to build a radar system which used separate transmitter and receiver locations, extra protection would be afforded to the radar receiver because the radar receiver would not broadcast its presence. Further, the passive radar receiver would be less vulnerable to classic anti-radar techniques such as anti-radar missiles or electronic counter measures. A passive radar system would require the presence of a usable host signal. The host signal would be cooperative if the transmitter and receiver were working together. A non-cooperative host would be a transmitter whose broadcast energy were being used without the transmitter's knowledge.

Several studies have been commissioned to explore methods of realizing a passive bistatic radar system. For example, the study of bistatic radar cross sections (5; 6; 8), separate host receiver synchronization methods, 1; 3; 4; 10), and a synthetic aperture mapping demonstration (1) are available. XonTech explored the possibility of using a non-cooperative host acquisition technique and delineated the receiver criteria for using such a separate host receiver system (4:21).

5

Historic Background of Radar Systems. The historic
background of radar systems is flecked with use of multi-
static systems. The early systems developed in Germany and
England were bistatic. An array of receive antennas were
placed at known distances from the transmitter antenna. The
radar returns were monitored and useful information was
obtained by triangulation between several receivers. The
use of fence radar systems employ this technique. Some of
the Early Warning nets used this technique (12:36-2).

During the Second World War, technological breakthroughs
eliminated the need for separate receiver and transmitter
antenna. As knowledge of radar waves increased, techniques
were developed for protecting the receiver from the trans-
mitter antenna power during transmission. Techniques used
included the use of recirculators and duplexers. The elimi-
nation of the need for the separate transmitter and receiver
antennas led to the development of the monostatic radar.
These systems were attractive due to the improvement in cal-
culation of range and doppler information. The classical
radar range and doppler equations (11:4) provided useful
range and velocity values. The radars were useful in devel-
oping air control radar systems. As more radar propagation
knowledge was gained, it became feasible to mount a radar on
an airborne platform. The radar was used to provide naviga-
tion and surveillance information (14:6).

Historically, the processing of the radar returns was
done with analog computing devices. The marriage of the

6

digital processor to the radar family has greatly expanded radar system capabilities. The growing level of sophistication of the Electronic Counter Measure (ECM) capabilities has generated a new interest in the Bistatic Radar System. The Bistatic Radar returns are subject to the same type of counter measures, but the ECM, for effective bistatic blackout, would require a system much broader in power and technical complexity (9:24).

Problem

An important aspect of the bistatic radar problem is the interpretation of the data which the system delivers. The bistatic system does not use the classical radar range equation (12:557). Additionally, the system will perceive different doppler shift (change in transmitted signal frequency) effects due to the movement between the transmitter, the target, and the receiver (15:25). The classical model has a doppler shift which is twice the velocity divided by the transmitted wave length (2V/L) (14:592). The doppler shift in bistatic model is due to the combined effects of the radial velocity between the transmitter and target divided by the transmitted wavelength (Vo/Lo) and the radial velocity between the target and receiver divided by the wavelength of the reflected frequency (V1/LN). The system is best understood using the concepts of isoranges and isodops. The isorange curve gives regions of constant range and is the solution of the bistatic radar range equation for a specific

set of input values. The isodop is a curve of constant velocity which results from the bistatic doppler equation.

The purpose of this study is to build an analytic computer program model to study the airborne bistatic radar case. The model will be used to develop isorange and isodop maps to explore the possible airborne bistatic system configurations (e.g., Air to Air, Air to Ground).

The bistatic radar problem can be solved for many configurations for the transmitter receiver pair. The model developed in this study is general in scope but is limited to pulse doppler radar waveforms. The general case is developed but the specific case study is limited to a High PRF (25,000 Hz), Multiple PRF (4), S-Band airborne receiver. The receiver is assumed to be capable of acquiring and processing the host transmitter waveform. The actual method for acquiring the signal is not a part of this study. This study concentrates on limitations imposed by the signal characteristics.

Definition of Key Terminology

The airborne bistatic radar system is composed of several components of the classic monostatic radar system. The configuration of these components, and more specifically, the roll of these components is the important issue in understanding the airborne bistatic case. The signal (waveform) properties of the host signal transmitting system determine the performance of the radar system. The receiver's acquisition of the signal requires techniques which vary

depending upon whether or not the system is cooperative or non-cooperative. For example, a cooperative system would be in constant contact (e.g., a secure data link) to assure beam synchronization while a non-cooperative system would most likely be constantly chasing the source beam in the "expected" trace region. The bistatic system is sensitive to the power limitations imposed by the classic radar range equation. Assuming the receiver acquires the signal, the signal characteristics have a direct effect on performance (range).

Major Components. The major components of the Bistatic system are the transmitter, target, and receiver. The bistatic receiver is separate from the transmitter by definition (15:1). The role of each component is important in quantifying system performance.

The airborne receiver is the key element of the bistatic system. It is responsible for acquiring the signals emitted by the transmitter. The emitted signal is acquired on two paths: A direct path between the transmitter and receiver and the bistatic reflected path from the transmitter to the target to the receiver. The airborne receiver platform is assumed to be a surveillance - listening - system which flys a constant elevation orbit in a sanctuary zone a considerable distance (100-200 Kilometers) from the transmitter.

The transmitter is any radar (airborne or ground based) which emits a waveform that can be processed by the receiver. The transmitter may be stationary or mobile.

9

The target is any object that reflects the transmitted energy and produces a bistatic reflection which is monitored by the receiver. The target has characteristics of cross section and velocity which affect the bistatic radar equations as a function of the radial distance and radial velocities.

Signal Properties. The bistatic system is capable of operating using cooperative and non-cooperative host transmitters. Accordingly, the acquisition and processing of the signals is a prime consideration. A PRIORI knowledge of the signals increases the accuracy of the information gleaned from the output of the receiver. This requires some practical considerations for system performance characteristics which are limited by bandwidth and host transmitter power.

There are several methods for signal acquisition proposed in the literature. A non-cooperative system requires the receiver to search the frequency spectrum for a waveform with the desired characteristics (4:2). The waveform must be capable of being processed by the receiver hardware. For example, a pulse doppler processing system may not be able to process a Continuous Wave Frequency Modulated (CW-FM) signal. A cooperative system could use flight path synchronization (9) or secure data links to periodically update the system synchronization (1).

Synchronization of the beam between the transmitter and the receiver is important (14:577). The transmitter beam systematically sweeps out a volume of space. The bistatic

signal reflections (returns) available during the sweep are limited by the beam shape and power density. A cooperative host-receiver system has the option of a direct data link to enhance signal synchronization and information. Knowledge of the beam sweep pattern will allow the receiver to search in the expected return area. A non-cooperative host system requires the same synchronization. Because the non-cooperative host receiver system is not capable of perfect phase synchronization, the phase information is not available to the receiver processor. The loss of phase limits the overall system performance but the loss of phase information does not preclude the use of non-cooperative hosts in pulse doppler radar applications.

A method to avoid the high cost of beam synchronization is the use of a multiple beam search antenna system (Figure 1). An array of beams searches the volume of space where the transmitter is providing illumination (9:39; 14:577). Beam synchronization is limited to systems where the expected transmitter sweep pattern can be replicated. For example, a scanning search radar system has physical limitations in antenna movement and pointing capabilities. A phased array which could change wavefront direction at whim without consideration of antenna orientation would be a poor host.

Acquiring the bistatic signal return does not guarantee any meaningful results from the receiver data processing system. The bistatic return is subject to multipath and clutter constraints as well as time of flight versus power

RECEIVER
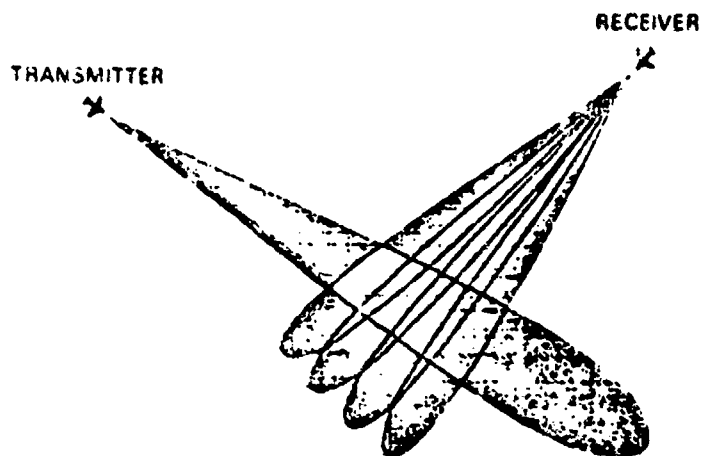
TRANSMITTER

Figure 1   Search With Multiple Receiver Antenna Beams

considerations.   Assumptions about the non-cooperative trans-
mitter waveform limit the potential host exploitation.
Further, a non-cooperative host which could reconfigure its
waveform parameters is a poor host candidate for the bistatic
receiver.   The ability to capture meaningful data is the
prime concern for the receiver.

The extraction of information contained in the bistatic
signal return is limited by the transmitter, target and
receiver.   The bistatic signal return contains information
in the time domain which is decoded into range information
of the transmitter-target-receiver family.   Additionally,

the bistatic signal return contains frequency domain information which decodes into the relative radial velocities of the system components. The frequency domain information is limited by the PRF and pulse width.

The transmitter power limits the detection region of the bistatic system because the receiver is assumed to be completely passive. Reliance on a host limits the range of the system under certain conditions. For example, Westinghouse asserts that under certain conditions (Bistatic baseline separation is less than 1.5 times the nominal Monostatic target detection range) the loss of coverage area relative to the Monostatic radar is insignificant (2:3-124). The passive nature of the receiver limits the radar range equation variables controllable by the receiver (e.g., SNR, front end temperature K, antenna gain, etc.). These variables are usually hardware dependent and not dynamically adjustable.

The Ovals of Cassini are used to describe the power limitations of a Bistatic System (12:36-41). The Ovals of Cassini describe the region where the receiver is capable of detecting useful information. Refer to Figure 5 and accompanying text for a complete development of the Ovals of Cassini.

The transmitter beam characteristics affect the system. The main beam lobe carries most of the power and is most capable of detection. The limitations imposed by jamming of the main lobe will not be as critical due to the bistatic

13

return geometry because the bistatic return pattern is not the same as the monostatic return (9:23). This study will not consider side lobe returns.

Physical Properties of the Transmitted Waveform. Physical properties of the transmitted waveform are critical in the analysis of the bistatic problem. A class of pulse doppler radar waveforms is examined in this study. The class is limited to a generic waveform which is realizable. The pulse repetition frequency, the pulse width, and receiver bandwidth are critical design parameters. Westinghouse asserts:

> These factors, as well as legal frequency allocation requirements, drive radar designs to operating in one restricted frequency band with an instantaneous bandwidth only wide enough to provide the range cell length needed by the system. For typical long range airspace surveillance radars, effective pulse widths in the vicinity of 0.5 to 2 microseconds limits the instantaneous bandwidth to about 0.5 to 2 MHZ [2:?-127].

The Pulse Repetition Frequency (PRF) is the frequency at which the transmitter emits pulses. The PRF is the reciprocal of the time between pulses (1/T). The use of multiple PRFs (11:114) increases the range effectiveness of the radar.

Clutter is any radar return (monostatic, bistatic, or multistatic) which is not desired. A large signal return due to background could hide a possible target. Clutter echos greatly distort the information being processed by the system. One of the secondary concerns of the bistatic radar range and doppler problem is the need to quantify the

clutter phenomena of the bistatic system. A clutter thresh-
old is usually established to limit the unwanted signal
returns on a system. The effects of reducing clutter will
have a significant effect on the detection of targets with
small radial velocities.

The doppler shift in a bistatic signal return is not
the same as the monostatic return. The equations are more
difficult because the transmitter and receiver are not
co-located. The bistatic doppler shift is a result of a
shift due to the radial velocity of the target to the trans-
mitter, and a second shift due to the radial velocity of the
target with respect to the receiver.

The solutions to the bistatic range and doppler equa-
tions result in solution families. These solution families
are more clearly expressed in graphical form using Isorange
and Isodoppler contours. The Isorange contour (Figure 2) is
the family of possible solutions to a radar range return.
Without any prior knowledge of the transmitter/receiver/tar-
get configuration, the isorange contour indicates possible
locations for the target. The isodoppler contours (Figure 3)
are the family of constant velocity curves (as a result of
doppler shift).

Advantages

Some advantages of multistatic systems are apparent
when applied to information gathering environments. Advan-
tages include:

ISORANGE = Γ (R1+R2)

R1

R2
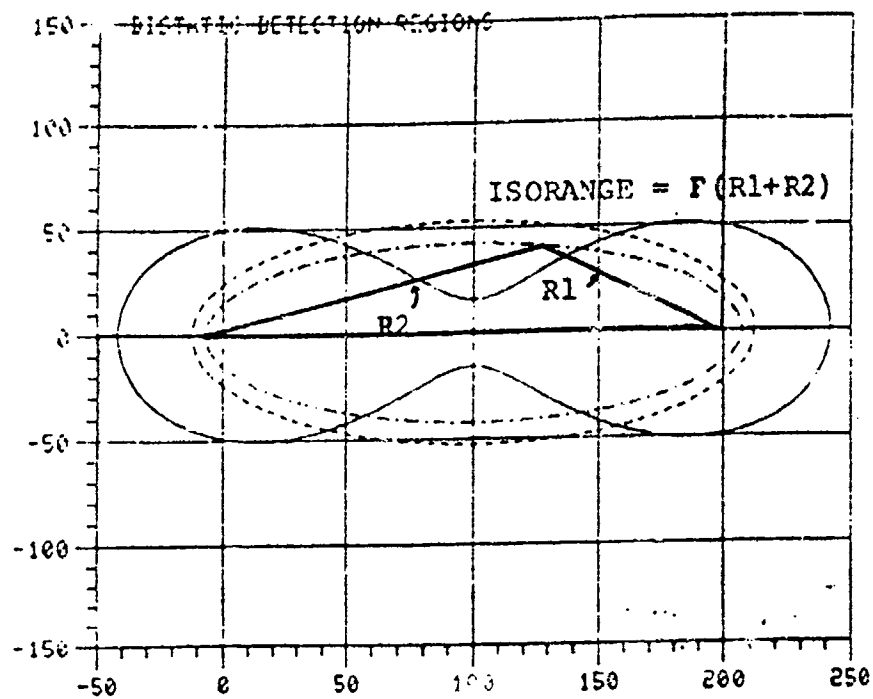
Figure 2   Isorange Curves

- 1000   - 2000   - 2000   - 1000

- 3000

R
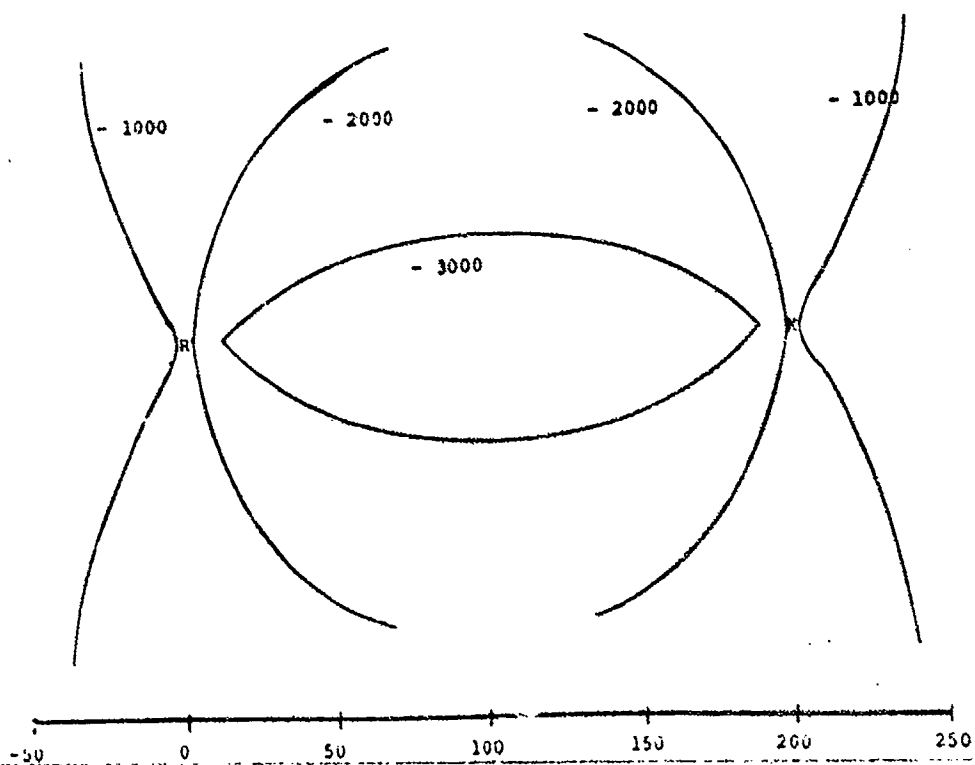
Figure 3   Isodoppler Curves

16

1. Undetectable position of the Receiver

2. Accuracy in Ranging

3. Operation of the Receiver in Sanctuary

4. Cost Savings

An airborne bistatic system would offer some surveil-lance advantages in that the radar receiver would not broad-cast its presence. Transmitter detection of the receiver is a function of the transmitter's power, coupled with the receiver's distance (two way), the radar cross section (RCS) of the receiver. The receiver could be outside the trans-mitter's detection region and still be well within the exploitation region.

Farina and Hanle have demonstrated that a multistatic ranging system is more accurate provided the target is within the triangulation perimeter (3:517). The airborne bistatic radar system could operate in the confines of a netted sys-tem but would require multiple receivers to do triangulation to improve accuracy. In general, the bistatic radar system will not be as accurate as a monostatic system.

If the radar could operate at great ranges (100-200 KM), the receiver is operating in a relatively safe zone or sanc-tuary. The limitations of the distance between the trans-mitter and receiver imposed by power, coupled with the lim-itations imposed by waveform, describe the safe zone oper-ating limits.

While the receiver would require more computing resources, the savings in design costs, by eliminating the

waveform generator portion of the airborne system, is an attractive trade-off option. Additionally, the savings in receiver platform fuel consumption due to weight elimination and power generation could be attractive.

Summary of Current Research

The Bistatic Radar Problem is a complex, multifaceted arena with many potential areas for investigation. Current issues being studied by the technical community include: Bistatic Cross Sections, Scintillation Effects, Polarization Effects of Returns, Synchronization Techniques, and Signal Acquisition Techniques.

The bistatic radar cross section is not the same as the monostatic radar cross section. The monostatic signal return is a function of the target distance and cross section. The bistatic cross section is generally larger because of the larger forward energy reflection (15:3). The cross section returns are dependent upon the type of material and the type of background. Many technical communities are working to develop models to analytically predict the returns due to targets, ground, sea, and terrain. Specific studies representing key areas of interest include:

1. RCS Prediction of Low Observable Coated Objects (5)

2. Ground Clutter (13)

3. Chaff (8)

4. Sea/Terrain Scattering Coefficients (4)

18

A Bistatic Synthetic Aperture Radar (SAR) Self Synchronization Technique has been proposed by Westinghouse as a result of their studies of bistatic radar platforms (1). The report outlines a synchronization method which could be used between a receiver and a cooperative host. The concept of a Bistatic SAR was proposed and demonstrated in the T-Bird program (Morenno). The T-Bird Program demonstrated the ability to gather data via a separate airborne transmitter receiver pair.

III. Development of the Bistatic Model

Defining the Parameters

The bistatic model used in this study assumes the use of a pulse doppler radar system. The model assumes the receiver hardware is capable of detecting and analyzing the radar return. The parameters used in the model are the common variables affecting any pulse doppler signal processing system. The model consists of a computer program which uses the parameters, formulas, and concepts explained in this chapter (see Appendix_A for a complete listing). The computer program assumes the default parameters of the E3A AWACS Waveform but can be modified interactively. The system parameters include:

        Pulse Repetition Frequency (PRF)
        Number of distinct carrier frequencies used (NPRF)
        Pulse Duration (TPULSE)
        Carrier Frequency (FO)
        Signal to Noise Detection Ratio (SNR)
        Transmitter Power (P)
        Gain of the Transmitter Antenna (GT)
        Gain of the Receive Antenna (GR)
        System losses due to physical construction (LOSS)
        Receiver Minimum Signal to Noise Detection Ratio (SNR)
        Average Target Radar Cross Section (RCS)
        Receiver Temperature (T)
        Receiver Bandwidth (BW)
        Signal to Clutter Power Ratio (SCR)
        Doppler Frequency Shift of the Clutter Cell (FSC)
        Area of the Clutter Cell (AC)
        Density of the Clutter Cell (SO)
        Receiver horizon to target depression angle (RSEL)
        Transmitter horizon to target depression angle (XSEL)
        Receiver baseline to target azimuth angle (RSAZ)
        Transmitter baseline to target azimuth angle (XSAZ)
        Transmitter Azimuth Beam width (XSAZ)
        Receiver Azimuth Beam width (RSAZ)
        Transmitter Elevation Beam Height (XSEL)

Receiver Elevation Beam Height (RSEL)
Bistatic Angle: Transmitter to Receiver as seen from
    target (A-B)
Out Of Plane Azimuthal Angle between beams (PHI)
Receiver Altitude (RALT)
Transmitter Altitude (XALT)

The bistatic airborne system model is developed in the
rectangular coordinate system (X, Y, Z). The Receiver/
Transmitter/Target set have specific physical relationships
(Figure 4). The receiver antenna is the base for all meas-
urements. The receiver antenna is assigned to position
X = 0, Y = 0, Z = RALT (RALT default is 9) because the
receiver is assumed to be airborne at a constant surveillance
elevation. The target can be anywhere in X, Y, Z space.
The direct path between the transmitter and the receiver is
known as the baseline in the bistatic model. Therefore, the
model assumes the transmitter is located at a point along
the X axis (X = SEP) and at an altitude Z = XALT. This
corresponds to position SEP, O, XALT. Note that all dis-
tances used in this model are in kilometers.

The number of parameters makes the assignment of mean-
ingful variables difficult. The use of some self imposed
rules helps to aid in clarity. The transmitter variables
are prefixed with X and the target variables are prefixed
with T. For example, the transmitter azimuth angle is coded
XAZ while the target azimuth angle is coded TAZ.

The basis for the mathematical development considers a
receiver at reference position 0, 0, RALT (X coordinate,
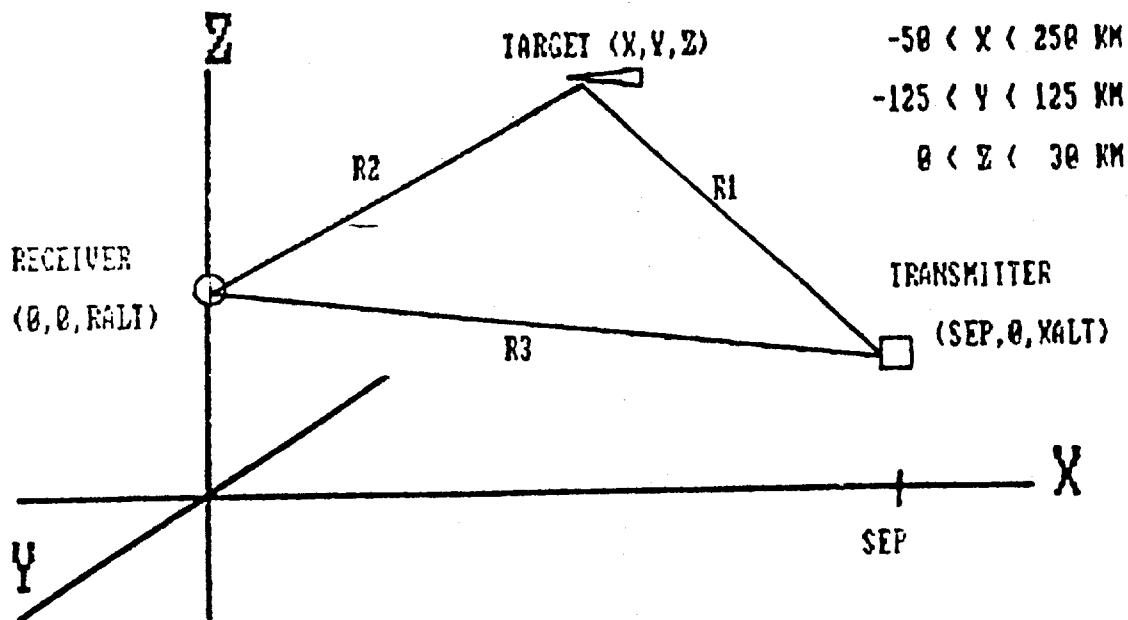
Figure 4   Bistatic Coordinate System

Y coordinate, Z coordinate); a transmitter at position SEP,

0, XALT; and a target anywhere in XYZ space such that:

```
 -50 < X - 250 kilometers
-125 < Y < 125 kilometers
   0 < Z <  30 kilometers
```

Radar Range Equation. Classical analysis of radar

problems begins with the radar range equation (12:19). The

equation contains the parameters of interest which are

affected by any radar system.

$$R^4 = \frac{P \; GT \; GR \; C^2 \; RCS}{(4\pi)^3 \; FO^2 \; BW \; L \; SNR \; T \; K} \tag{3.1}$$

22

P = Power of the Transmitter (Watts)

GT = Gain of the Transmitter Antenna

GR = Gain of the Receive Antenna

L = System Losses Due to Physical Construction

SNR = Receiver Minimum Signal to Noise Ratio Detection

C = Speed of Light (3×10^8 Meters per Second)

K = Boltzmann's Constant (1.38×10^{-23} Joules per Degree Kelvin)

π = 3.1416

RCS = Average Target Radar Gross Section (Square Meters)

T = Receiver Temperature (Degrees Kelvin)

BW = Receiver Bandwidth (Hertz)

FO = Transmitted Frequency (Hertz)

R = Distance from Transmitter/Receiver to Target (Meters)

Note that the radar range equation can be rewritten:

$$K = \frac{P\ GT\ C^2}{4\ \pi\ R1^2\ FO^2} * \frac{RCS}{4\ \pi\ R2^2} * \frac{GR}{4\ \pi\ BW\ L\ T\ SNR}$$

< Transmitter >   < Target >   <   Receiver   >

Note the separation of the parameters into transmitter, target, and receiver dependent areas. These are the parameters which are varied to examine the bistatic case.

Bistatic Geometry. The geometry of the bistatic radar system is ellipsoid. The transmitter and the receiver are the foci of the ellipsoid. The surface of the ellipsoid

23

forms a family of solutions to the isorange equation problem. The general equation for an ellipsoid (13:51) is:

$$(\frac{X-Xo}{A})^2 + (\frac{Y-Yo}{B})^2 + (\frac{Z-Zo}{C})^2 = 1 \qquad (3.2)$$

In this case, the parameters B and C are equal because the ellipsoid has no eccentricity. The values of A and B are developed later in the minimum and maximum isorange solution section.

Recall from Figure 4 that the model requires the receiver to be positioned at point 0, 0, RALT and the transmitter to be positioned at some point along the X axis specified as SEP, 0, XALT. If the transmitter is at the same altitude as the receiver (XALT = RALT), equation 3.2 becomes:

$$(\frac{X-SEP/2}{A})^2 + (\frac{Y}{B})^2 + (\frac{Z-RALT}{B})^2 = 1 \qquad (3.3)$$

The detection region of the bistatic system is limited by the power of the transmitter. The transmitted waveform must have enough power to travel (Figures 4 and 6) a distance from the transmitter to the target (R1) and then a distance from the target to the receiver (R2) and still provide a large enough signal to noise power ratio (SNR) to insure accurate detection. The maximum detection range is given by a set of curves referred to as the Ovals of Cassini as shown in Figure 5. Any target inside the oval provides

24
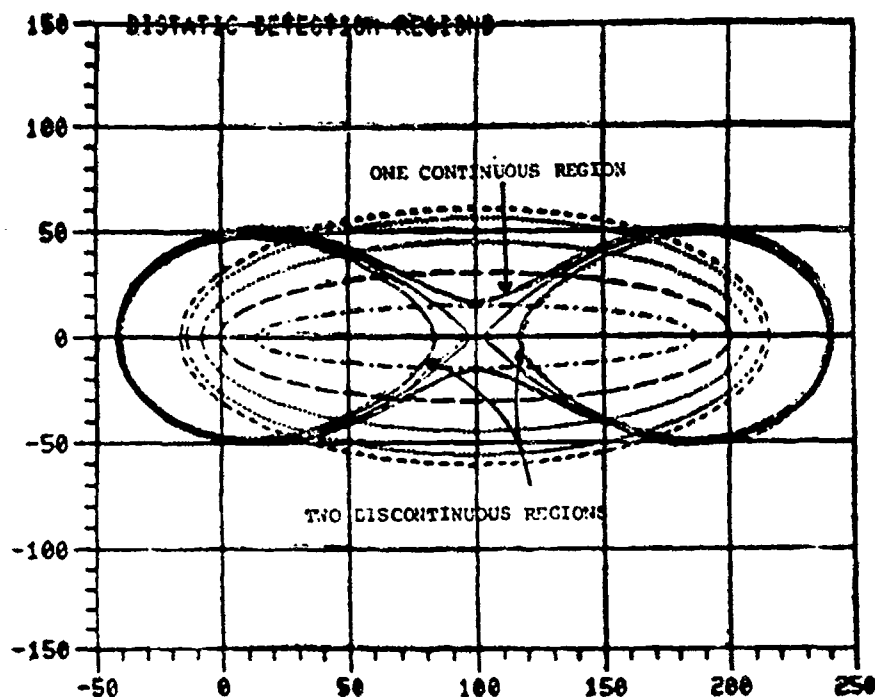
Figure 5   Ovals of Cassini

at least the minimum signal to noise ratio at the receiver antenna. Note that it is possible to have two completely disjoint regions of detection. The transmitter power affects the detection region. The solution set to the ovals of Cassini will yield either two distinct regions, two adjacent regions, or one region.

The bistatic radar cross section of a target varies from the monostatic cross section. Investigation into the error between monostatic and bistatic cross section has shown that the Bistatic Monostatic Equivalence Theorem is valid only for small bistatic angles (15:3). The model allows for changing the RCS, but offers no monostatic bistatic comparison.

25

The bistatic radar range equation varies from the mono-
static by simple substitution of Eq (3.5) into Eq (3.1).
The power radiated from the transmitter spreads in a sphere.
The gain of the transmitter antenna accounts for the direc-
tionality of the density. The radiated power has a specific
density which is a function of the square of the distance
from the target to the transmitter. At that point, the cross
section of the target reflects some of the power. The
reflected power acts as if the target were an isotropic
radiator. The reflected power spreads in a sphere. The
density of the reflected power is a function of the square
of the distance between the target and the receiver.

$$R^4 = R1^2 \, R2^2 \qquad (3.5)$$

Observe that the maximum range (R^4) is a constant. The
Range constant (R^4) is a product of the squares of the trans-
mitter to target range (R1) and the target to receiver range
(R2). Therefore, the bistatic radar range equation becomes:

$$R1^2 \, R2^2 = \frac{P \; GT \; GR \; c^2 \; RCS}{(4\pi)^3 \; FO^2 \; BW \; L \; SNR \; T \; K} \qquad (3.6)$$

The transmitter and target coordinates and the Pythag-
orean Theorem combine to show:

$$R1^2 = (SEP - X)^2 + Y^2 + (Z - XALT)^2 \qquad (3.7)$$

20

Applying the same to the target receiver pair:

$$R2^2 = x^2 + y^2 + (Z - RALT)^2 \qquad (3.8)$$

Therefore:

$$R^4 = [(SEP - X)^2 + Y^2 + (Z - XALT)^2]$$

$$[x^2 + y^2 + (Z - RALT)^2] \qquad (3.9)$$

Ability of System to Perform. The Bistatic Radar Iso-
range curves (Figure 6) are calculated by extracting informa-
tion from the radar return signal. The specific measure-
ments are the Distance (SEP) between the transmitter and the
receiver, the Angle (ON) between the transmitter and the
target as measured from the receiver, and the time difference
(DT, Figure 7) between receiving a direct signal (transmit-
ter to receiver) and the next large return (transmitter to
target to receiver).

The geometry of the airborne bistatic radar system
yields ellipsoidal isorange curves. The key to understand-
ing the equations is to have a consistent frame of reference.
Although the system may consist of three airborne entities
(target, receiver, and transmitter), the coordinate system
is defined by making the receiver the reference point. This
point will be relative in XYZ space by always viewing the
receiver as being at the origin of the X and Y axes and at
altitude Z = RALT KM (0,0,RALT). All distances will be
measured with respect to the receiver. The "BASELINE" is

27
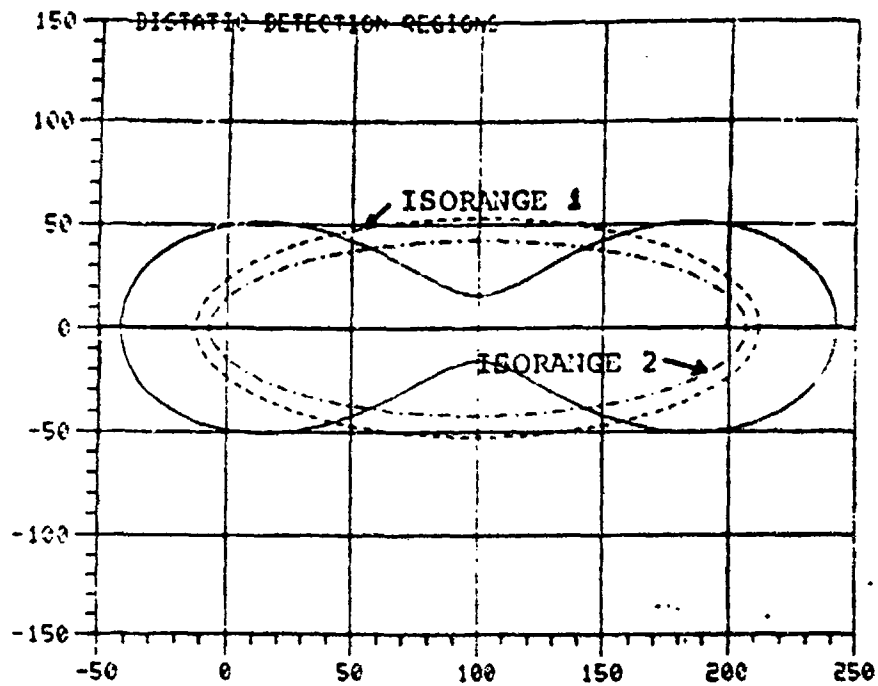
Figure 6   Ellipse of Constant Range
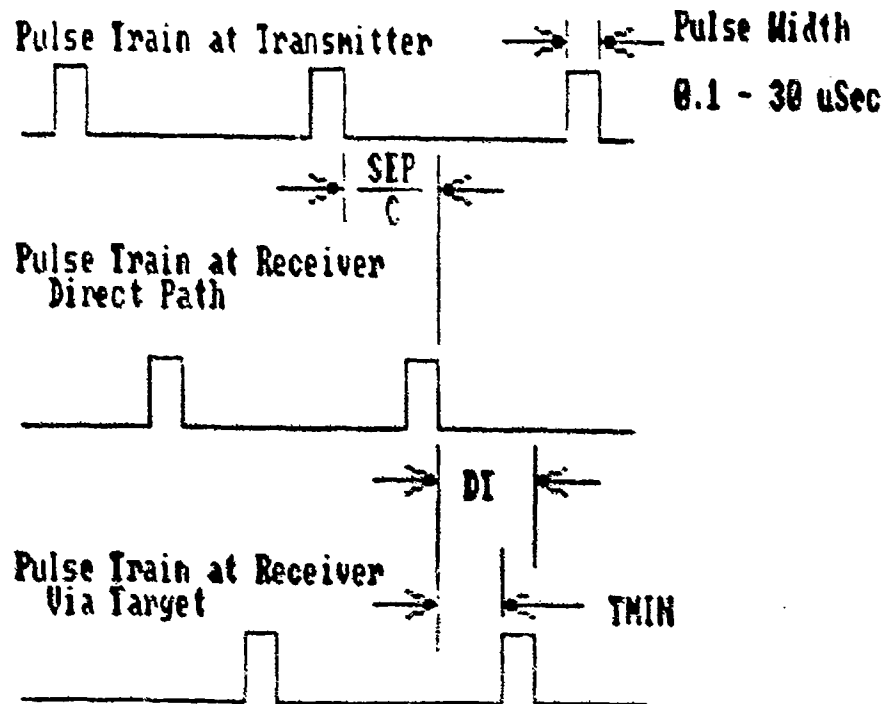
Figure 7   Pulse Reception Characteristics

29

the imaginary line between the receiver and the transmitter.
The baseline lies along the positive X axis. Therefore the
transmitter is always located at some separation distance
and some altitude point   (SEP,0,XALT).

The time required for a signal to travel from the trans-
mitter to the target and then to the receiver is DT seconds
longer than the time required to travel directly from the
transmitter to the receiver. The relationship of the trian-
gular distances is:

$$R1 + R2 = C * DT + SEP \qquad\qquad (3.10)$$

This result is a family of solutions (R1 + R2) which
traces out an ellipsoid. The point on the surface of the
ellipsoid is a solution of interest. This family of solu-
tions is called an isorange. Obviously, a different DT
measurement results from a different isorange curve.

Figure 7 points out several areas of concern. As DT
grows small, separation of the pulses (TMIN) in the pres-
ence of noise becomes extremely difficult. Even if there
were an absence of noise, separation of the pulses is dif-
ficult as TMIN approaches zero. At some point, the two
pulses will overlap. The receiver is unable to extract any
information from the signal. This occurs when the distance
between the target and receiver grows small (SEP = R2) or
when the bistatic angle (A-B) approaches 180 degrees. The
receiver must be able to detect two separate signals. This

blind area is a disadvantage of the bistatic model. The
blind zone is treated in more depth in the ISOMIN Develop-
ment Section.

The receiver antenna is assumed to be a directional
scanning antenna. The receiver knows where it is looking at
all times. Therefore, when a signal is detected, the
bistatic angle (A-B) is known within the limits of the antenna
beam shape. If multiple beams are used, a volume of space
can be scanned with greater resolution. Knowing the bistatic
angle (A-B) gives a specific solution to the isorange family.
The accuracy of solution is directly dependent upon the beam
width of the antenna which in turn limits the ability to
separate the target and transmitter returns. Several alter-
nate solutions have been offered for solving this problem
(9:1).

One possible solution comes from basic geometry. This
short derivation is provided to show one possible method
for receiver calculation to target location. Knowing (A-B)
the calculation of R1 and R2 is possible. Therefore, the
target range and direction can be determined. R2 is derived
from the Law of Cosines:

$$R3 = \sqrt{SEP^2 + (XALT - RALT)^2}$$

$$R1^2 = R2^2 + R3^2 - 2\ R2\ R3\ CCS\ (A-B$$

and because the bistatic relationship to a family of solu-
tions,

$$R1 + R2 = \text{Isorange Constant (K8)}$$

then,

$$R1 = K8 - R2$$

$$(K8 - R2)^2 = R3^2 + R2^2 - 2\ R2\ R3\ \cos\ (A-B)$$

$$K8^2 - 2\ K8\ R2 + R2^2 = R3^2 + R2^2 - 2\ R2\ R3\ \cos\ (A-B)$$

Rearranging,

$$R2\ (2\ R3\ \cos\ (A-B) - 2\ K8) = R3^2 - K8^2$$

and finally,

$$R2 = (R3^2 - K8^2)\ /\ (2\ R3\ \cos\ (A-B)$$

$$-2\ K8)$$

Limiting Regions

The Power Limited Region. Note that the general solution to Eq (3.9) is greatly simplified by limiting the observation to a specific set. In the specific case, the parameters SEP, Z, XALT, and R^4 are constants which are dependent on the transmitter receiver target geometry and hardware. Equation (3.9) is solved for a specific Y in terms of X by use of the quadratic formula (13:32). The solution may yield one of the three region shapes shown in Figure 5 depending upon the values assigned to the constants.

Let $$C1 = (Z - RALT)^2 \qquad\qquad (3.11)$$

$$C2 = (Z - XALT)^2 \qquad\qquad (3.12)$$

31

Then, from (3.9):

$$R^4 = [(SEP - X)^2 + Y^2 + C2] [X^2 + Y^2 + C1] \qquad (3.13)$$

Expanding the terms and rearranging yields:

$$0 = Y^4 + (X^2 + (SEP-X)^2 + C2 + C1) Y^2 + X^2$$

$$((SEP-X)^2 + C1)) + C1 [(SEP-X)^2 + C2] - R^4 \quad (3.14)$$

Note that this is in quadratic form:

$$AY^4 + BY^2 + C = 0$$

So:

$$Y^2 = \frac{-B \pm \cdot \sqrt{B^2 - 4\,A\,C)}}{2A}$$

And therefore:

$$Y = \pm \cdot \sqrt{Y^2}$$

Where:

$$A = 1$$

$$B = X^2 + (SEP-X)^2 + C2 + C1$$

$$C = X^2 [(SEP-X)^2 + C2] + C1 [(SEP-X)^2 + C2] - R^4$$

Let:

$$C3 = C2 + C1 + SEP^2 \qquad (3.15)$$

$$C4 = -2\,SEP \qquad (3.16)$$

32

$$C5 = C1 \cdot C4 \qquad (3.17)$$

$$C6 = C1 \cdot SEP^2 + (C1 \cdot C2) - R^4 \qquad (3.18)$$

$$B4 = X^2 - X \cdot SEP + C3/2 \qquad (3.19)$$

$$CC = X^4 + C4 \cdot X^3 + C3 \cdot X^2 + C5 \cdot X + C6 \qquad (3.20)$$

Then solving for solutions of Y:

$$Y = \pm - \sqrt{- B4 + \sqrt{(B4^2 - C3)}} \qquad (3.21)$$

Isorange Formula Development. It was shown earlier that the solution set to the bistatic range equation resulted in a family of solutions. The family of solutions occupy an ellipsoidal space. That is to say, the solution set is the surface of an ellipsoid. Recall Eq (3.2). This equation can be solved for the roots of one variable (X, Y or Z). For this model, a plane of interest is specified (Z = Z'). The general solution set for Y in terms of X is:

$$\left(\frac{Y}{B} \right)^2 = 1 - \left(\frac{Z - RALT}{B} \right)^2 - \left(\frac{X - SEP/2}{A} \right)^2 \qquad (3.22)$$

Then,

$$Y^2 = B^2 - (Z - RALT)^2 - \left(\frac{B \cdot (X - SEP/2)}{A} \right)^2 \qquad (3.23)$$

or, considering both roots as solutions:

$$Y = \pm \sqrt{B^2 - (Z - RALT)^2 - \left(\frac{B \cdot (X - SEP/2)}{A} \right)^2} \qquad (3.24)$$

33

This general equation holds only for an airborne to airborne transmitter receiver pair at the same altitude. It is more realistic to assume that the non-cooperative transmitter could be at an altitude of up to 30 kilometers. Allowing for this possibility adds complexity to the equation but only through a rotation and translation of the X and Z axes.
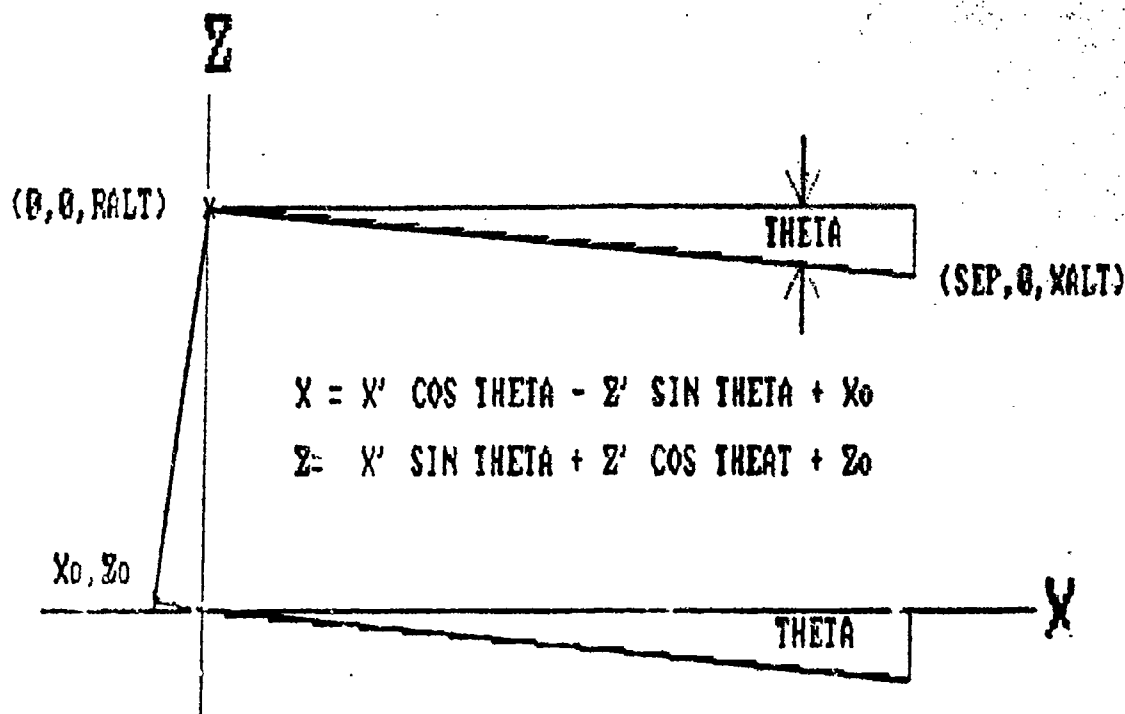
Figure 8 Rotation of the Bistatic Model

The rotation angle is THETA = ARCSIN (XALT - RALT) / SEP. This makes the coordinates of the new axis X = RALT SIN THETA, Y = 0, Z = RALT (1 - COS THETA). The transforming equations (13;36) are then:

$$X = X' \text{ COS THETA} - Z' \text{SIN THETA}$$

$$+ \text{ RALT SIN THETA} \qquad (3.25)$$

$$Z = X' \text{SIN THETA} + Z' \text{COS THETA}$$

$$+ \text{ RALT } (1 - \text{COS THETA}) \qquad (3.26)$$

Substitution of these transforms into the general equation yields:

$$Y^2 = B^2 - (X' \text{ SIN THETA} + Z' \text{COS THETA} + \text{RALT COS THETA})^2$$

$$- (B/A)^2 (X' \text{COS THETA} - \text{SIN THETA} (Z - \text{RALT})$$

$$- \text{SEP}/2)^2 \qquad (3.27)$$

Assigning the following simplifying variables to the constants and dropping the prime notation gives:

$$C12 = \frac{B^2}{A^2} \qquad (3.28)$$

$$\text{SIN THETA} = \text{STHETA} = (\text{XALT} - \text{RALT}) / \text{SEP} \qquad (3.29)$$

$$\text{COS THETA} = \text{CTHETA} = \text{COS (ARCSIN THETA)} \qquad (3.30)$$

$$C10 = Z \text{ COS THETA} - \text{RALT COS THETA} \qquad (3.31)$$

$$C11 = Z \text{ SIN THETA} - \text{RALT SIN THETA} + \text{SEP}/2 \qquad (3.32)$$

The equation in terms of X and Y yields,

$$Y = \pm \sqrt{B^2 - (X \text{ STHETA} + C10)^2 - C12 (X \text{ CTHETA} - C11)^2}$$

$$(3.33)$$

35

Isorange Blind Zone (ISOMIN). The minimum isorange is

the solution which yields the direct path between the trans-

mitter and receiver. No target information is available

along this path (4; 5; 15). Therefore, a starting point

must be found at some practical range. A logical starting

point is the edge of the "Isorange Blind Zone".

The blind zone (Figure 9) is the area which results

from the receiver being unable to determine where the pulse

traveling along the direct path between the transmitter and

the receiver stops and the pulse traveling along a reflected

path starts. This blind zone will be a function of the pulse

duration (TPULSE). The minimum blind zone isorange is twice

the pulse duration times the speed of light, plus the separa-

tion distance between the transmitter and receiver.

$$R3 = \sqrt{SEP^2 + (XALT - RALT)^2} \qquad (3.34)$$

$$ISOMIN = (2 * TPULSE * C) + R3 \qquad (3.35)$$

Beyond the blind zone the isoranges need to be incre-

mented at some regular interval up to some limiting factor.

The model limit is 300 Kilometers. Often the Pulse Repeti-

tion Frequency (PRF) will dictate a maximum isorange.

Maximum Isorange (ISOMAX). The PRF limitation occurs

when the transmitted PRF becomes so high that the bistatic-

ally reflected pulse is not received until, during or after

a second pulse is received on the direct path. At a low PRF,

36
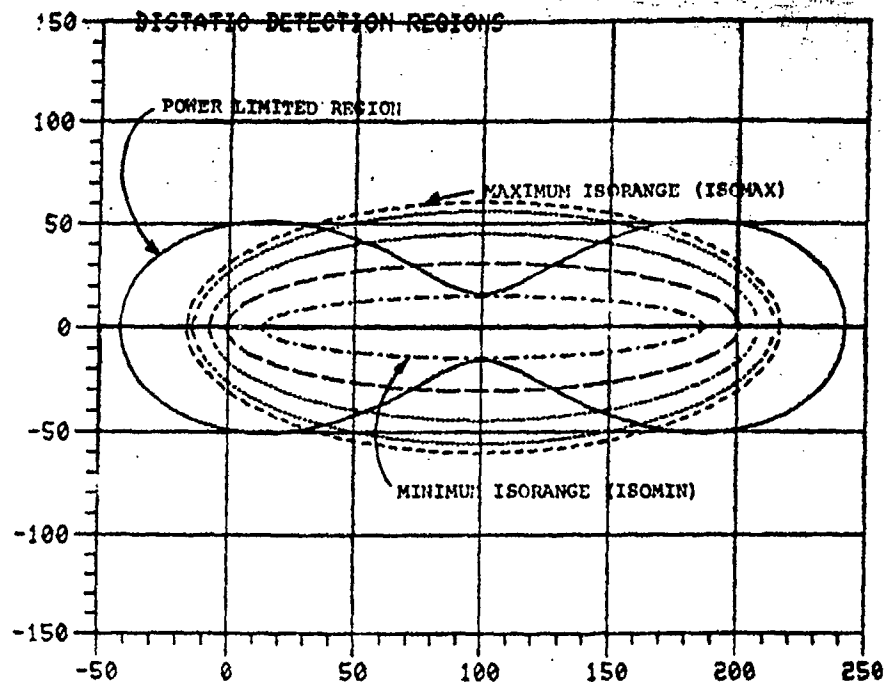
Figure 9 Isorange Detection Region

the direct pulse is received followed some time later by the
target reflected pulse. However, when the PRF becomes suf-
ficiently high, the time of reception of the bistatic pulse
can be delayed long enough so that it overlaps the next
direct pulse. The overlap begins to occur when the leading
edge of the second transmitted pulse arrives before the
trailing edge of the first bistatically reflected pulse (4:9):

$$R1 + R2 + TPULSE \ C > (C \ / \ PRF) + R3 \qquad (3.36)$$

This leads to the exclusion region (Figure 9) of the ellipse
defined by:

37

$$R1 + R2 = (C / PRF) + R3 - TPULSE\ C \qquad (3.37)$$

But, if multiple PRFs (NPRF) are used by the transmitter, the exclusion region can extend beyond these bounds (12:114). The maximum isorange (ISOMAX = R1 + R2) is therefore extended to:

$$ISOMAX = (NPRF * C / PRF) + R3 - TPULSE\ C \qquad (3.38)$$

Incrementing the Isoranges. It is often necessary to draw several isorange curves between the minimum (ISOMIN) and the maximum (ISOMAX) isorange curves. Choosing 10 Kilometers as an interval, the first isorange is needed such that ISOMIN < ISO(I) < ISOMAX.
Letting,

$$Q = INT\ [\ ISOMIN\ /\ 10\ ];\ Greatest\ Integer \qquad (3.39)$$

$$ISO(I) = I * Q * 10 \qquad (3.40$$

I is the incremented from 1 to some number (K) such that ISO(I) does not exceed ISOMAX or 300 Kilometers (limit of the model). For each ISO(I), a unique solution set for the equation is determined. From the properties of the ellipsoid (13:38):

$$A = ISO(I)/2 \qquad (3.41)$$

and because

$$B^2 = A^2 - (SEP/2)^2 \qquad (3.42)$$

$$B = \sqrt{A^2 - (SEP/2)^2} \qquad (3.43)$$

For example, to determine A and B for ISO(I) = ISOMAX, the term A simplifies to:

$$A = (NPRF * C / PRF + R3 - TPULSE C) / 2 \qquad (3.44)$$

Likewise, B reduces to:

$$B = \sqrt{[[(NPRF * C / PRF) - TPULSE C] * [(NPRF * C / PRF)}$$

$$+ (2 * R3) - TPULSE C]] / 2 \qquad (3.45)$$

Note that in most applications, TPULSE << 1/PRF. This simplification holds for most systems as the prf is reduced to extend the system visibility. The zones are then separated by ellipses whose characteristics A,B reduce to:

$$A = ((NPRF * C / PRF) + R3) / 2 \qquad (3.46)$$

and,

$$B = \sqrt{[[NPRF * C / PRF] * [(NPRF * C / PRF) [(2 * SEP)]] / 2}$$

$$(3.47)$$

Development of the Bistatic Doppler Equation Model

The doppler shift of a signal for the monostatic system is a function of the frequency of transmission and the velocities of the transmitter, target, and receiver. The velocity of the target is always measured radially from the transmitter to the target. The radial velocity causes a positive (target and receiver are closing), negative (target and receiver are separating) or zero (target and receiver remain at a constant distance) shift in frequency.

The classical doppler model is based on a single frame of reference (transmitter and receiver are co-located). The doppler shift of a transmitted wave propagating through space from the transmitter, striking an object (the target), and being returned to the receiver is twice the radial velocity of the target divided by the transmitted wave length. The shift in the frequency between the transmitted signal and the returned signal is the doppler shift (12:69). Analytically:

$$FD = 2 \, V \, / \, L \qquad\qquad (3.48)$$

Where:

    FD = Doppler Shift (Hertz)

    V = Radial Velocity Between Two Objects (Meters per
        Second)

    L = Wave Length of the Transmitted Frequency (Meters)

The frequency, wave length, and speed of light relationship (12:69) is:

$$C = L \ FO \qquad (3.49)$$

Therefore,

$$FD = 2 \ V \ FO \ / \ C \qquad (3.50)$$

The bistatic doppler model is not as easily derived. This results because the transmitter and the receiver are not located at the same point in space. In fact, it is conceivable to imagine the transmitter receiver pair separated by large distances (several hundred kilometers). The net doppler shift of the transmitted frequency (FF) is a function of the radial velocity of the transmitter with respect to the target and a second doppler shift due to the radial velocity of the target with respect to the receiver.

The transmitter will broadcast a signal at a given Frequency (FO). The target will reflect the signal at some doppler shifted frequency due to the radial velocity of the transmitter target pair (FD1). The reflected signal can be modeled as if it were an isotropically radiated signal at some new frequency (FN = FO + FD1). The signal will be acquired at the receiver at some second doppler shifted frequency (FF) which is a function of the radial velocity of the target/receiver pair (V1).

$$FD = V1 \ / \ L \qquad (3.51)$$

$$= V1 \ FO \ / \ C \qquad (3.52)$$

In the model, the transmitter and target velocities are specified as a vector with magnitude and direction. The velocities are user specified as a magnitude (VT,VX), some angle of azimuth heading (TAZ,XAZ) and some angle depicting rate of climb (TEL,XEL). The azimuth direction is always referenced to the baseline which is the direct path between the transmitter and receiver. The receiver is assumed to be flying a constant elevation surveillance orbit. The transmitter will also have a zero angle for TEL (but is not model limited). The transmitter, whether ground based or airborne, is assumed to be very limited in maneuverability due to the physical characteristics (construction) of the antenna. An obvious exception would be a Phased Array Radar which will not be considered here.

The radial velocities of the transmitter/target (target/receiver) pair are computed for any X,Y,Z point using vectors. The radial velocity is the vector dot product. The velocity vector is dotted into the unit vector separating the two objects.

$$V = \bar{A} \cdot \bar{B}$$

The velocity vectors V1, V2 are decomposed into X,Y,Z components for ease of operation.

$$VXZ = VX \sin XEL \quad ; \text{Z component of Transmitter} \quad (3.53)$$

$$VXY = VX \cos XEL \sin XAZ \quad ; \text{Y component of Transmitter} \quad (3.54)$$

42

$$VXX = VX \cos XEL \cos XAZ \quad ; \quad X \text{ component of Transmitter}$$

$$(3.55)$$

$$VTZ = VT \sin TEL \quad ; \quad Z \text{ component of Target} \quad (3.56)$$

$$VTY = VT \cos TEL \sin TAZ \quad ; \quad Y \text{ component of Target}$$

$$(3.57)$$

$$VTX = VT \cos TEL \cos TAZ \quad ; \quad X \text{ component of Target}$$

$$(3.58)$$

The general form of the dot product (16:635) is:

$$\bar{A} \cdot \bar{B} = a1 \ b1 + a2 \ b2 + a3 \ b3 \quad\quad (3.59)$$

The vector from the receiver to the general point XYZ is:

$$\bar{A} = X \ \bar{i} + Y \ \bar{j} + (Z-RALT) \ \bar{k} \quad\quad (3.60)$$

The vector from general point XYZ to the transmitter is:

$$\bar{B} = (SEP-X) \ \bar{i} - Y \ \bar{j} + (XALT-Z) \ \bar{k} \quad\quad (3.61)$$

Both vectors A and B must be normalized. The normalization is required as only the unit position vector is required. Therefore:

$$\text{Let } A1 = \sqrt{X^2 + Y^2 + (Z-RALT)^2} \quad\quad (3.62)$$

and

$$\text{Let } B1 = \sqrt{(SEP-X)^2 + Y^2 + (XALT-Z)^2} \quad\quad (3.63)$$

43

Recall that the vector between two points has direction as well as magnitude. Because the vector from X, Y, Z to SEP, O, XALT is the negative of the vector from SEP, O, XALT to X, Y, Z, a factor of -1 must be included in the transmitter component to insure the doppler shift is negative when separating and positive when closing. The radial velocity of transmitter with respect to the target due to the velocity of the transmitter alone is then:

$$V1R = [(X - SEP) \; VXX + Y \; VXY + (Z - XALT) \; VXZ] / B1$$

$$(3.64)$$

The radial velocity of the transmitter with respect to the target due to the velocity of the target alone is then:

$$V2R = [(SEP - X) \; VTX - Y \; VTY + (XALT - Z) \; VTZ] / B1$$

$$(3.65)$$

The total radial velocity due to the transmitter target pair is:

$$VTOT = V1R + V2R \qquad (3.66)$$

The doppler shift is a function of the frequency and wave length:

$$V = L \; FD \qquad (3.67)$$

$$FD1 = VTOT / L$$

or, by combining and simplification:

$$FD1 = [(SEP-X)\ (VTX - VXX) + Y\ (VXY - VTY)$$

$$+ (XALT-Z)\ (VTZ - VXZ)\ ]\ /\ (B1\ L) \quad (3.68)$$

At this point the new radiated frequency is the transmitted frequency plus the doppler shift. The new frequency is:

$$FN = FO + FD1 \quad (3.69)$$

And of course, this new frequency has a new wave length:

$$LN = C\ /\ FN \quad (3.70)$$

The radial velocity of the target with respect to the receiver due to the velocity of the target (model assumes receiver is zero reference) is then:

$$V2R = [VTX\ X + VTY\ Y + VTZ\ (Z-RALT)]\ /\ A1 \quad (3.71)$$

Using the same development, the second doppler shift is:

$$FD2 = V2R\ /\ LN$$

$$= (-1)\ [VTX\ X + VTY\ Y + VTZ\ (Z-RALT)]\ /\ (A1\ *\ LN)$$

$$(3.72)$$

The net doppler shift is:

$$FF = [(SEP-X)\ (VTX - VXX) + Y\ (VXY - VTY)$$

$$+ (XALT-Z)\ (VTZ - VXZ)]\ /\ (B1\ L)$$

$$- [VTX\ X + VTY\ Y + VTZ\ (Z-RALT)]\ /\ (A1\ LN) \quad (3.73)$$

This is the general form of the solution space. A map
of the isodoppler contours is desired. An array (TABLE) is
set up to hold the general solution set for the region of
interest. A plane of interest is examined by specifying
the Z plane (altitude) desired. For example, if the plane
of interest is the doppler contours of the ground plane
(Z = 0), the array is scanned for contour information and
a table of values is generated. A contour map (isodoppler
lines) is constructed by a hand drawing the contour lines
on the map. The doppler value equations are nonlinear and
do not yield to a simple plotting routine.

Clutter

Clutter Parameters. Clutter is the unwanted radar
echo from an object or background (12:470). Clutter is
usually the radar return from a ground cell, insects, birds,
or possibly a storm cell. The clutter power is often larger
than any possible target power signal. This occurs because
the radar cross section of a clutter cell is much larger
than that of a probable target. The radar designer is con-
cerned with the characteristics of the unwanted signal
because techniques are available to enhance the detection
of targets if the clutter can be removed. Clutter signal
properties can be predicted. Therefore, the designer builds
"filters" to modify the signal returns in order to find prob-
able targets. The largest clutter return comes from ground
reflections.

The properties of interest are the Signal to Clutter
Power Ratio (SCR), the doppler frequency shift (FSC) of the
clutter cell, the area (CAP) of the clutter cell and the
density (SO) of the clutter cell. Monostatic and bistatic
radar are affected by these parameters. However, the cal-
culation and modeling of the system parameters for the
bistatic model changes significantly. For example, the
bistatic transmitter and receiver beams may have different
shapes. Even if the beam shapes were the same, the area
illuminated by transmitter would not be the same as the area
scanned by the receiver (Figure 10).
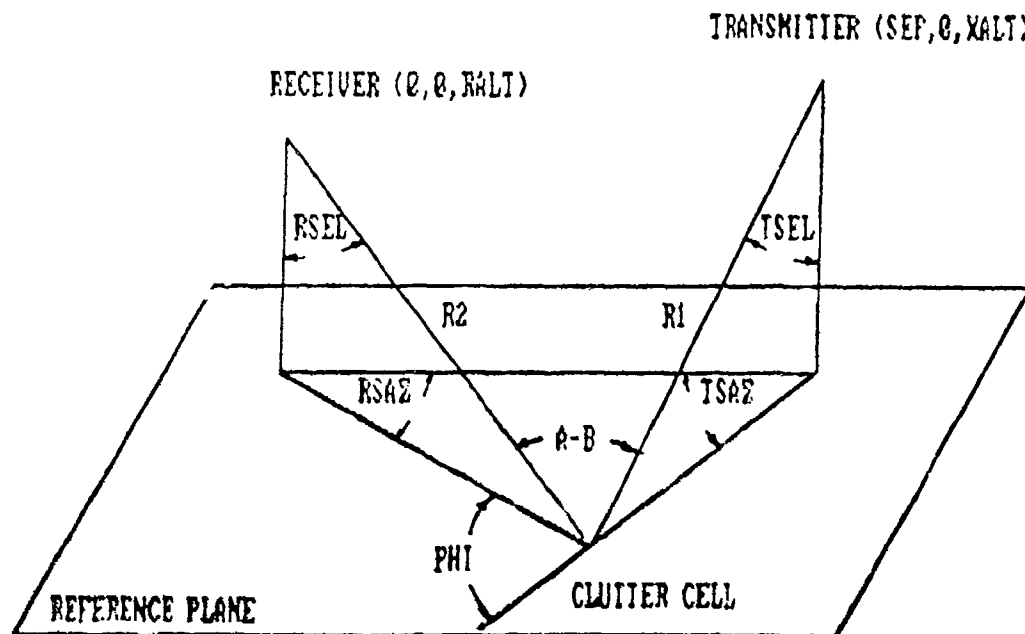
Figure 10   Geometry of the Clutter Cell

Signal to Clutter Ratio.   Signal power is radiated from
the transmitter to the target and then to the receiver.

47

The target will reflect an amount of power proportional to its radar cross section. The reflected power has an intensity and doppler shift. The clutter cell behind the target also reflects energy. The signal power (in terms already defined) is:

$$S = \frac{P \; GR \; GT \; RCS \; C^2}{(4\pi)^3 \; R1^2 \; R2^2 \; FO^2} \qquad (3.74)$$

The clutter power has the same equation with slight modification. The surface clutter cross section is defined as:

$$RCS = SO \; AC \qquad (3.75)$$

Where:

SO = Surface Cross Section per Unit Area

AC = Radar Cross Sectional Area of Illumination

The bistatic case modifies AC to mean the common area between the transmitter beam and the receiver beam. Figure 10 illustrates the common area for several possible cells. The Surface Cross Section is determined from a model which results from experimental data (15:20-23). SO varies depending upon the composition of the surface. For example, sea and forest clutter have different values. Several bistatic models have been developed to explore the SO phenomenon. References (5) and (15) catalogue many models and much of the research in this area.

48

The clutter power is:

$$C = \frac{P \ GR \ GT \ AC \ SO \ C^2}{(4\pi)^3 \ R1^2 \ R2^2 \ FO^2} \qquad (3.76)$$

Dividing Eq (3.78) by Eq (3.80), the Signal to Clutter Ratio is:

$$SCR = \frac{RCS}{SO \ AC} \qquad (3.77)$$

Clutter Cell Area. The clutter area is dependent upon the beam shapes and the processing equipment. The clutter cell is either beam width limited, resolution time limited, or doppler frequency limited (15:12). This model uses the Resolution time limited cell area developed by Weiner and Kaplan (15:16). The bistatic models for clutter assume the flat earth model. The clutter cell area for low grazing angle conditions (RSEL < 30 degrees) is defined as:

$$AC = \frac{R1 \ XSAZ \ SEC^2}{2 \ BW} \left(\frac{A - B}{2} \right) \ ; \ XSAZ < RSAZ \ R2/R1 << 2 \ RAD$$

or: $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ (3.78)

$$AC = \frac{R2 \ RSAZ \ SEC^2}{2 \ BW} \left(\frac{A - B}{2} \right) \ ; \ RSAZ < XSAZ \ R1/R2 << 2 \ RAD$$

Where:

RSEL = Receiver Horizon to Target Depression Angle

(Degrees)

XSAZ = Transmitter Azimuth Beam Width (Radians)

49

RSAZ = Receiver Azimuth Beam Width (Radians)

A-B = Angle [Transmitter to Receiver as seen from Target] (Radians)

Using the Law of Cosines and trigonometric identities, it can be shown that the term:

$$SEC^2 \frac{(A - B)}{2} = \frac{4 \ R1 \ R2}{2 \ R1 \ R2 + R1^2 + R2^2 - SEP^2 - (RALT - XALT)^2}$$

(3.79)

Therefore, AC can be estimated in terms of system position. It is assumed that the transmitter beam width (XSAZ) is known or at least a good estimate can be made.

Surface Cross Section Per Unit Area. Figure 11 shows an estimate of the Surface Cross Section Density Model (13:21). The graph values (for 3G Hz only) have been modeled by the second order equation:

$$SO = \sqrt{(X-90) \ 3.21111} \ -32 \ ; \ 90 < X < 270$$

(3.80)

or:

$$SO = \sqrt{(90-X) \ 10.000} \ -32 \ ; \ 0 < X < 90$$

$$; \ 270 < X < 360$$
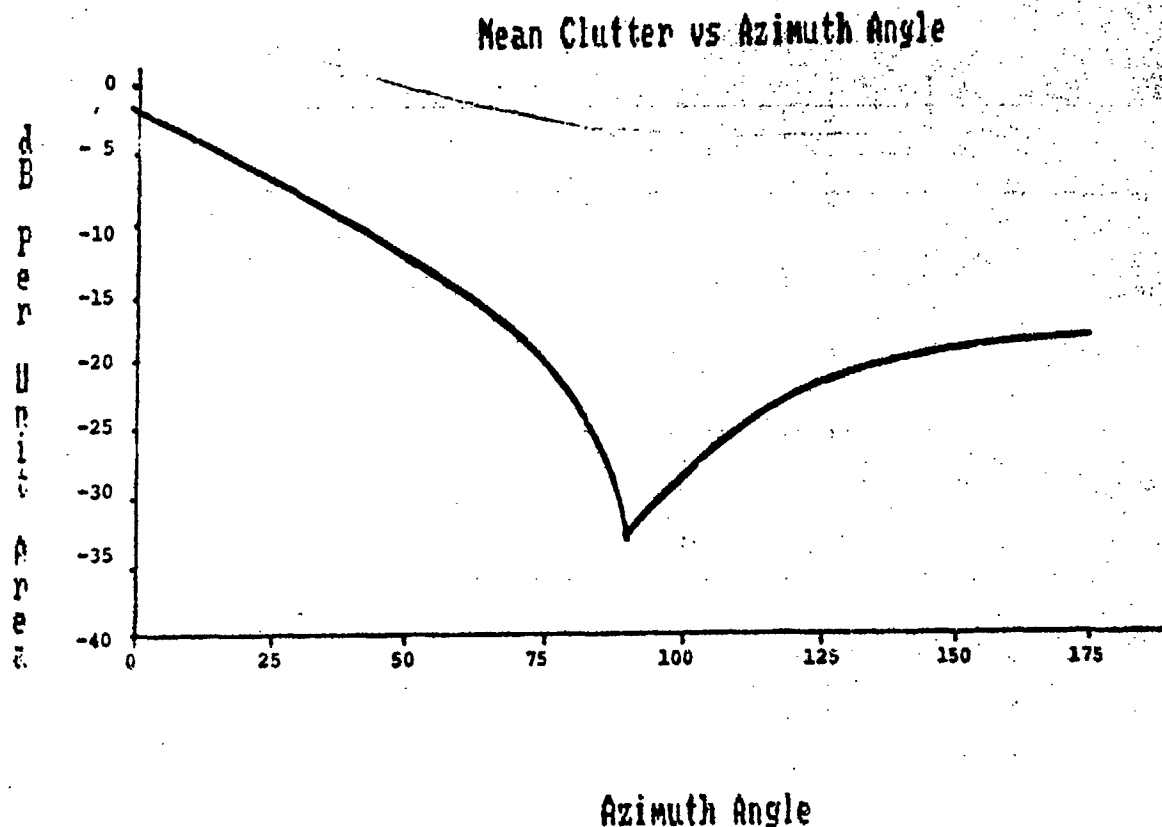
Mean Clutter vs Azimuth Angle

Figure 11   Mean Clutter Cross Section Per Unit Area

Weiner has shown that this general model can be extrapolated to other grazing angles by the addition of a correction term (13:20) to the value obtained from the graph.   The correction term is:

$$COR = \frac{PHI \cdot ADJ}{180} \qquad (3.81)$$

Where:

$$ADJ = -8 \text{ dB} \quad ; \quad (XSEL + RSEL)/2 < 1.5 \qquad (3.82)$$

or:

$$ADJ = 9.5 \text{ Log}_{10} \left((XSEL + RSEL)/2 \right) - 9.5 \quad ; \quad (XSEL + RSEL)/2 > 1.5$$

51

Where:

      PHI = Out of Plane Azimuthal Angle Between Beams

      XSEL = Transmitter Depression Angle

      RSEL = Receiver Depression Angle

<u>Doppler</u> <u>Spread</u> <u>of</u> <u>Clutter</u> <u>Cell</u>. The clutter cell power
is concentrated in the frequency domain about the cell dop-
pler shift (Figure 12). By estimating the width of the
clutter cell frequency shift, the receiver can dynamically
"filter" the returned signal. The ground clutter cell dop-
pler frequency shift varies as the geometry of the common
beam area changes. The equations in the Clutter section are
used to calculate the doppler shift of any specific point.
A method for estimating the difference in the maximum and
minimum doppler shifts of any clutter cell is required.
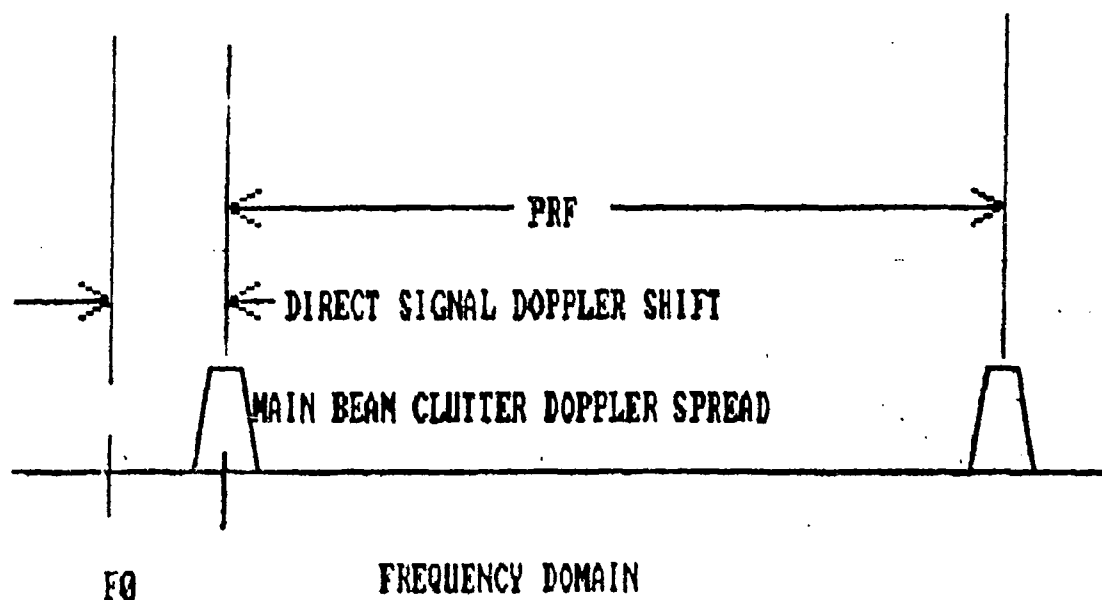
Figure 12 Clutter Power in the Frequency Domain

The model assumes the use of scanning and illumination beams with width (degrees in azimuth) and height (degrees in elevation). The parameters XWAZ, XWEL, RWAZ, and RWEL define the transmitter and receiver beam widths and heights respectively. A simple method for determining the doppler spread is to estimate the spread based on the beam widths. This is done by calculating four points for each beam. These points are approximately on the 3dB contour of the beam (Figure 13). A distance measure is made to each of the eight points. The four smallest distance measures dictate the four points used to estimate the doppler frequency spread. This is done by calculating the doppler shift to the four points using Eq (3.77). The minimum value is subtracted from the maximum value to obtain the estimate of the frequency shift. This method is used in Subroutine DOPSD, Appendix A.
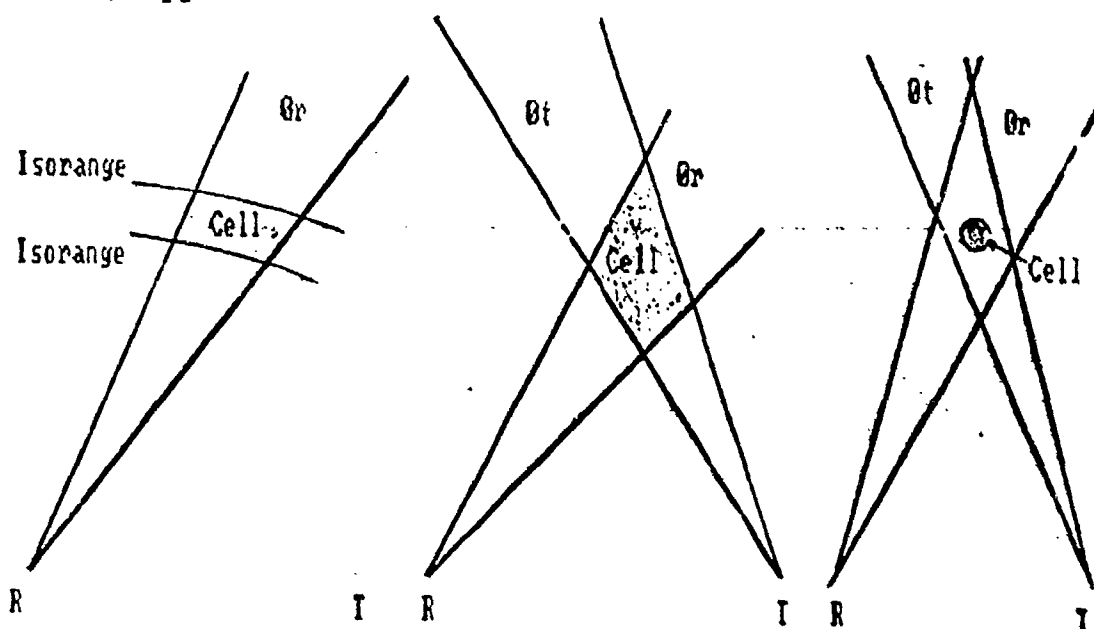
Figure 13 Geometry of Common Beam Area

53

Summary

The equations developed in this chapter are used in the Bistatic Radar Computer Model. In this chapter the limits of the model were defined. These limits included the X, Y, Z region of interest as well as the transmitter, receiver, and target parameters. These equations are the foundations upon which the computer model was built. The computer model allows the operator to change the values of the system from the default values. Figure 14 shows a sample menu. Based on the values entered by the operator, a plot is generated (Figure 15). This plot shows the isorange and power limitation contours.

```
CURRENT VALUES ARE DEFINED AS:
          TARGET              TRANSMITTER              RECEIVER
1  VELOCITY  •   600.00    6  VELOCITY  •  1200.00  18    TEMP  •   300.00

2  AZ ANGLE  •    90.00    7  AZ ANGLE  •    61.00  19    SNR   •     6.50

3  EL ANGLE  •     0.00    8  EL ANGLE  •     0.00
4        RCS •     1.75    9     POWER  •  0.0100  20    LOSS  •     6.50

5  Z PLANE   •     0.00   10  ALTITUDE  •     9.00  21    SEP   •   200.00

                         11      GAIN  •    40.00  22    GAIN  •    40.00

                         12   CARRIER  •     3.00  23      BW  •     1.00

                         13   BEAM WD  •     1.50  24  BEAM WD  •     1.50

                         14   BEAM HT  •     6.00  25  BEAM HT  •     6.00

                         15       PRF  •   25000  26      ALT  •     9.00

                         16  PULSE WD  •     6.00
                         17     # PRF  •         3
ENTER OPTION NUMBER [1-26] TO CHANGE VALUE
OR 27 TO CONTINUE
OR 28 TO ABORT
```

Figure 14   Computer Model Menu
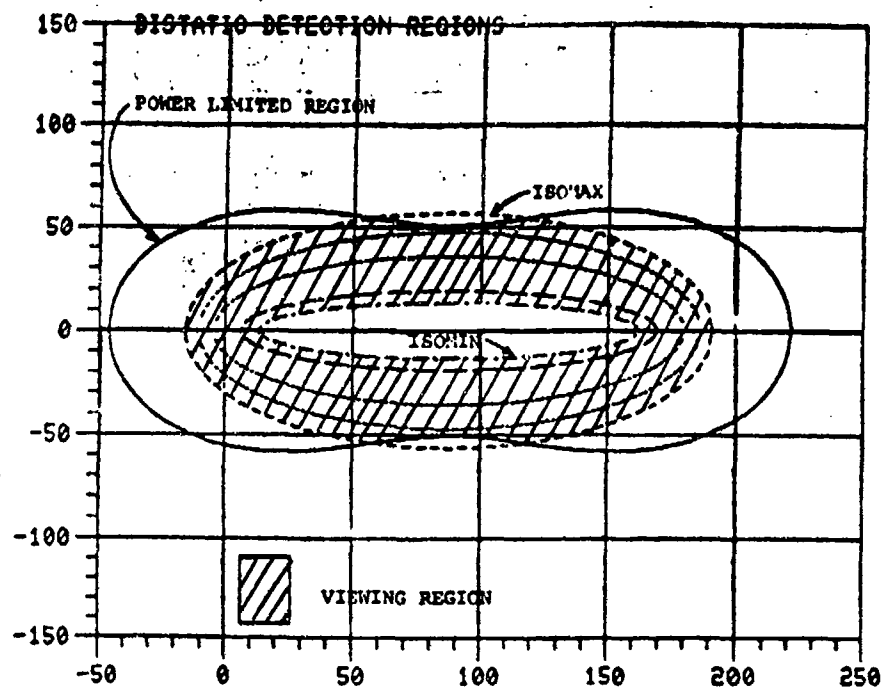
Figure 15   Bistatic Coverage and Exclusion Regions

IV. Exercising the Model

Introduction

This chapter outlines a generic form of the bistatic
radar model and demonstrates the effects of changing the
parameters of interest. The interactive software provides
many of the parameters which may be changed by the user when
exercising the model. This chapter demonstrates the effects
of transmitter and receiver hardware (power, waveform, etc.),
platform motion, and platform orientation on the bistatic
detection regions, the doppler effects, the signal to clutter
ratio and the doppler spread of the received signal. Finally,
a typical scenario is illustrated. For all cases used in
this section a generic bistatic set is assumed and changes
are shown relative to the generic set. The generic model
has parameters as shown in the sample computer menu (Figure
16). The parameter units and range of acceptable values are
displayed when changing any of the 26 parameters.

Limiting Regions

The Power Limited Region. The detection region which
is limited by the transmitter and receiver hardware is
described by the Ovals of Cassini. Figure 17 shows the
bistatic detection region for the ground plane $(Z = 0)$.
Decreasing transmitter power causes a collapse of the ovals
as demonstrated in Figure 18. Finally, Figure 19 shows the

CURRENT VALUES ARE DEFINED AS:
                 TARGET   TRANSMITTER   RECEIVER
1 VELOCITY =   600.00   6 VELOCITY = 300.00   18   TEMP =   300.00
2 AZ ANGLE =   0.20   7 AZ ANGLE =   0.00   19   SNR =   6.50
3 EL ANGLE =   0.00   8 EL ANGLE =   0.00
4   RCS =   1.75   9   POWER = 0.0100   20   LOSS =   6.50
5   Z PLANE =   0.00   10 ALTITUDE =   5.00   21   SEP =   200.00
                          11   GAIN =   40.00   22   GAIN =   40.00
                          12   CARRIER =   3.00   23   BW =   1.00
                          13   BEAM WD =   1.50   24 BEAM WD =   1.50
                          14   BEAM HT =   6.00   25 BEAM HT =   6.00
                          15   PRF = 25000   26   ALT =   9.00
                          16 PULSE WD =   5.00
                          17   # PRF =   3
ENTER OPTION NUMBER [1-26] TO CHANGE VALUE
OR 27 TO CONTINUE
OR 28 TO ABORT

Figure 16   Bistatic Model Parameter Menu (Generic Set)
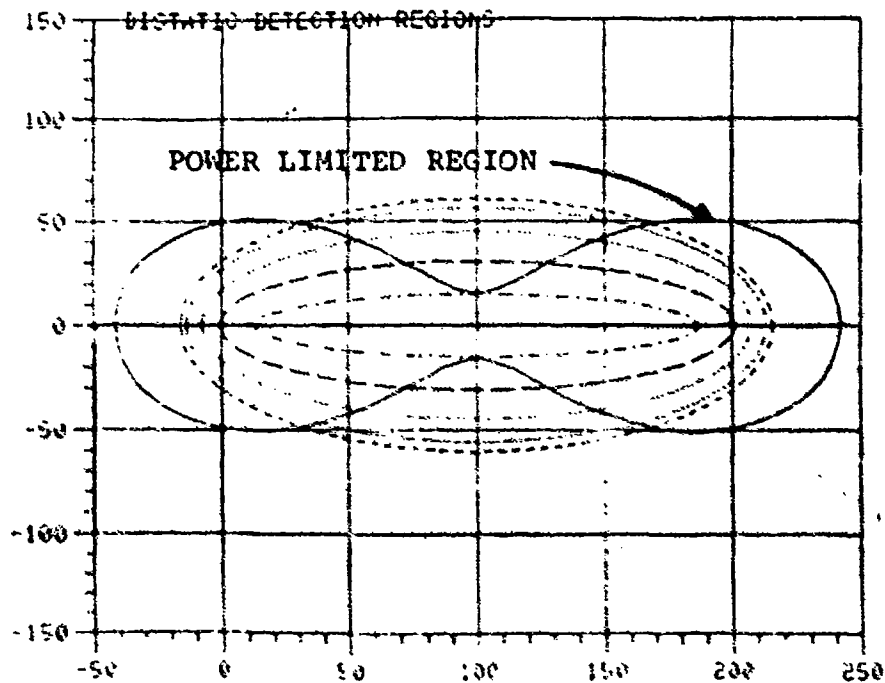
Figure 17   Generic Detection Region (Power = 0.01 Megawatts)

57
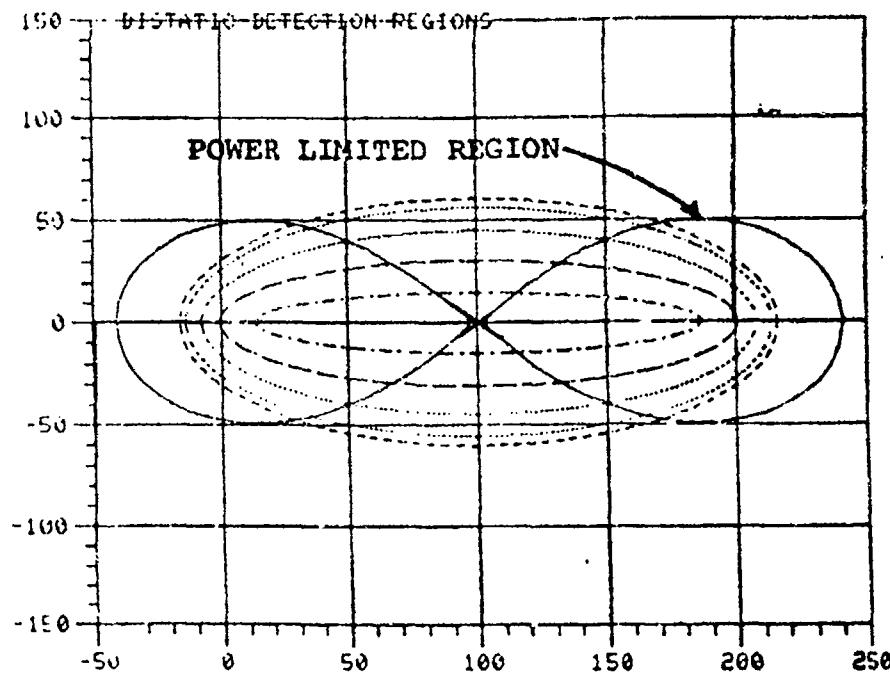
Figure 18   Detection Region (Power = 0.0095 Megawatts)
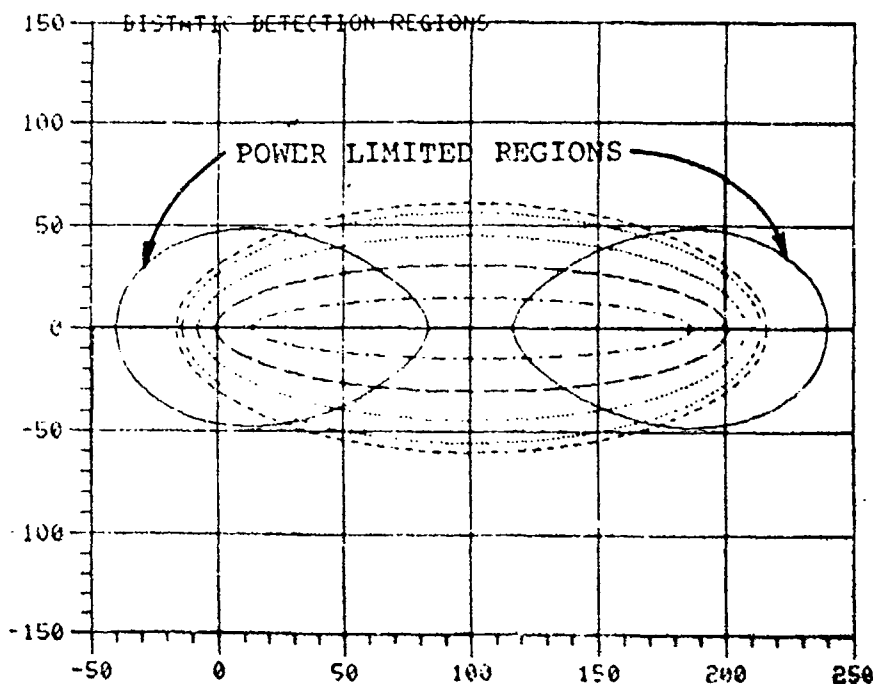
Figure 19   Detection Region (Power = 0.0090 Megawatts)

detection region when an even smaller amount of power is
used and the ovals divide into two specific regions.

The shape of the detection region changes as a function
of the platform separation distance (SEP). Figures 20 and
21 display the change in the detection region as the separa-
tion region between the transmitter and receiver decreases.

Figure 20 Detection Region (Separation = 190 KM)
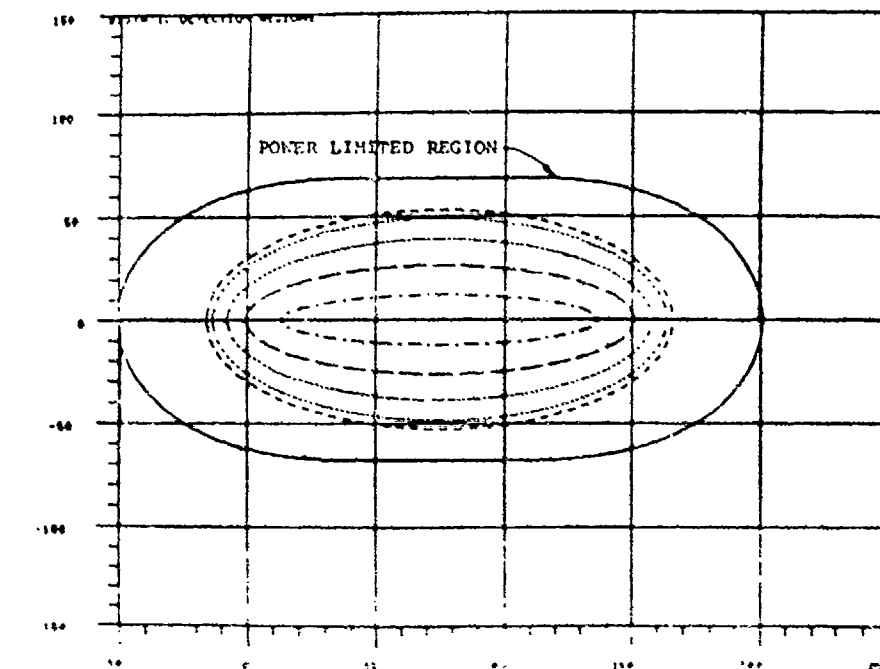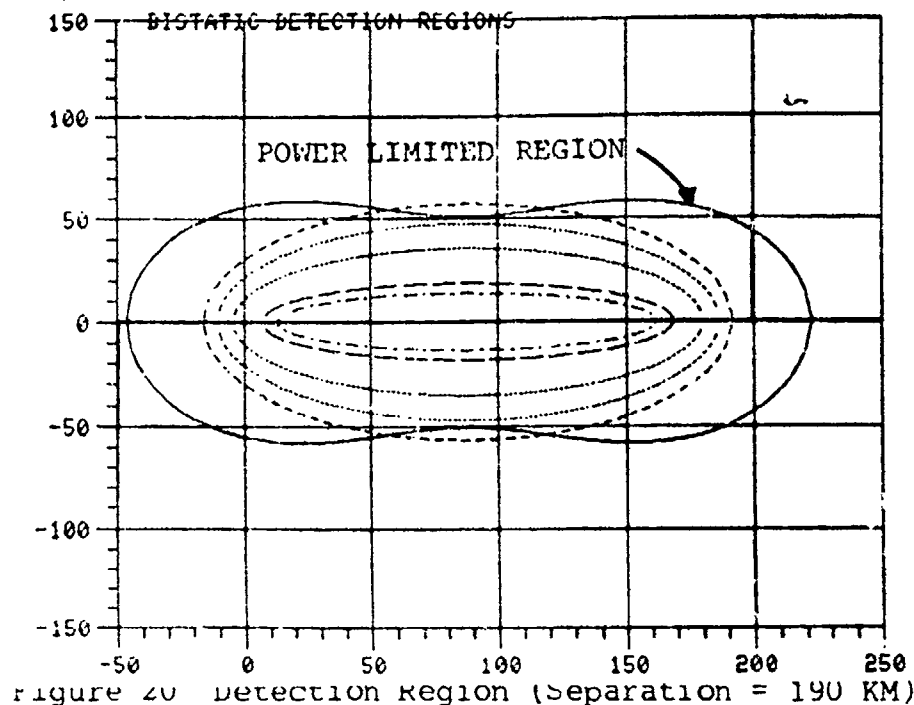
Figure 21 Detection Region (Separation = 160 KM)

59

Changing any of the parameters which effect the range
constant (R^4) yields similar results. Recall from Eq (3.5)
(3.6) and (3.9) that the range constant is a function of the
transmitter and receiver hardware as well as the target
location and cross section. The model takes into considera-
tion varying receiver and transmitter altitudes. Altitude
changes affect the geometry of the model by tilting the
ovals and ellipsoids producing an asymmetric figure. An
example of an airborne to ground pair is shown in Figure 22.
The detection region varys but is not quite as dramatic as
the change in the waveform limited characteristic regions
defined by the isorange curves.
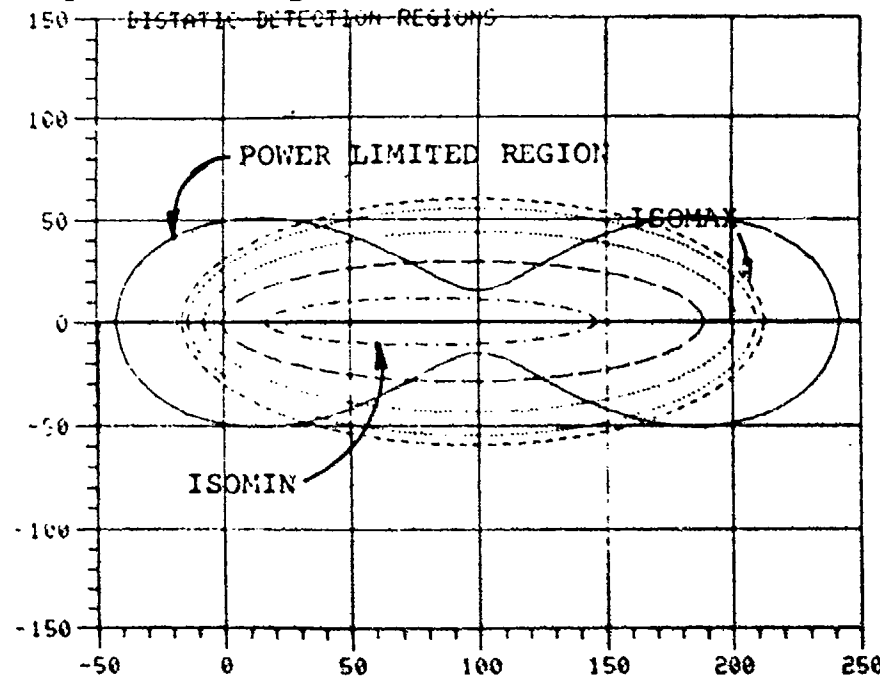
Figure 22   Airborne Receiver to Ground Transmitter

Waveform Limited Regions.

Evaluation of the Blind Zone (ISOMIN). The blind
zone is the region between the transmitter and receiver,

defined by an ellipsoid, where the receiver cannot detect
any target. Recall from the ISOMIN Development Section
Eq (3.38) that the blind zone is defined by the isorange
curve (ISOMIN):

ISOMIN = 2*TPULSE*C+SEP

The ISOMIN curves shown in Figures 16 thru 22 are for
pulse widths of 5 microseconds. It is easily demonstrated
that a longer pulse significantly increases the width of
the blind zone. Figures 17 and 23 demonstrate the effect of
increasing the pulse width from 5μs to 30us.
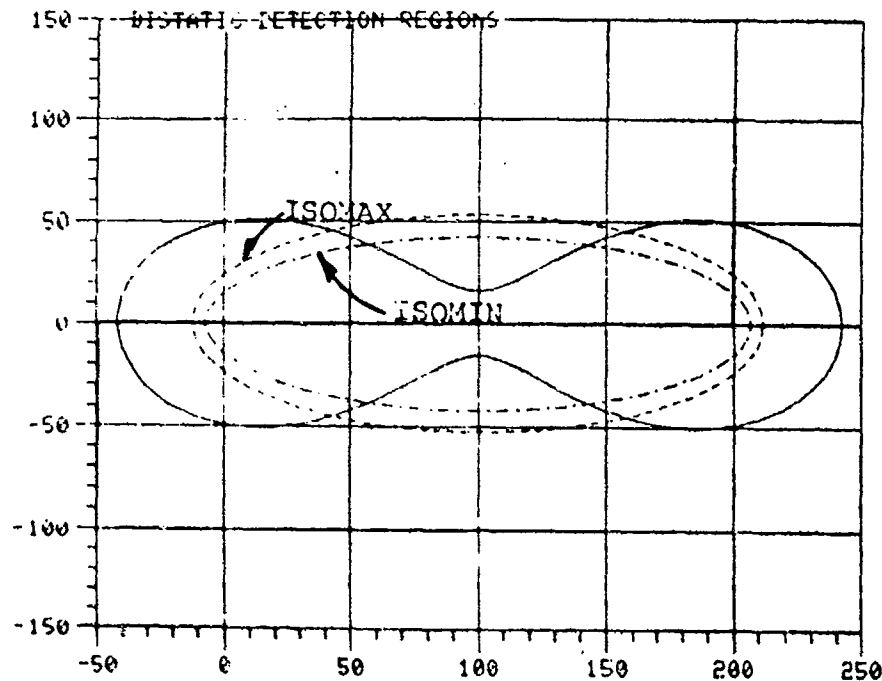
Figure 23   Detection Region for Pulse Width 30 Microseconds

The width of the blind zone ellipsoid can be shown to be:

$$WIDTH = SORT (ISOMIN^2 - R3^2) \qquad (4.1)$$

Table I lists the ISOMINs for a constant separation of 200 KM.

TABLE I

Comparison of Pulse Width,
Isomin and Ellipsoid Width

Pulse Width (microseconds)	ISOMIN (kilometers)	Ellipsoid Width (kilometers)
.1	200.06	4.6
1.0	200.60	15.5
5.0	203.00	34.8
10.0	206.00	49.4
15.0	209.00	60.6
20.0	212.00	70.3
25.0	215.00	79.9
30.0	218.00	86.8

When the data is put into graphical form, it is easy to recognize that a small pulse width is desirable to minimize the blind zone.

Evaluation of the Maximum Range (ISOMAX). The maximum visibility of the bistatic system was shown to be a function of the pulse repetition frequency (PRF), the number of distinct pulse repetion frequencies (NPRF), and the pulse width (TPULSE). Examination of Eq (3.44) yields the following observations: increasing the pulse width will lower the maximum range (compare Figure 17 to Figure 23); increasing the prf decreases the viewing area (Figure 17 versus Figure 25); decreasing the prf increases the maximum viewing area (Figure 26 versus Figure 17); and increasing the number of
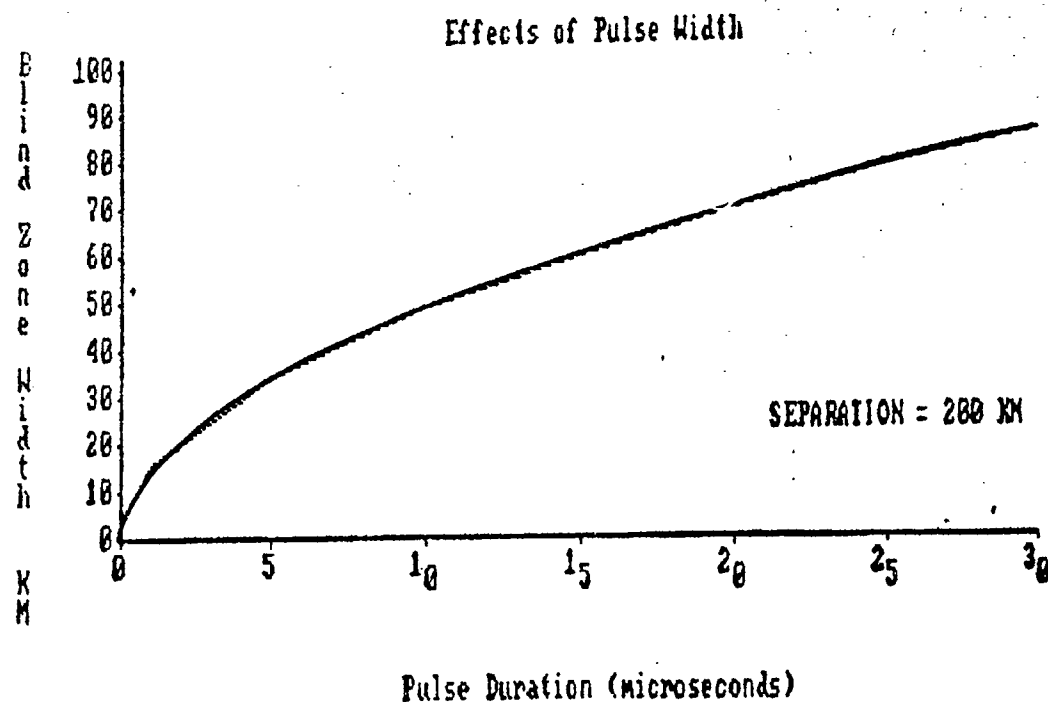
Figure 24   Effects of Pulse Width on Blind Zone

prf multiples increases the maximum range (Figure 27 shows a
multiple of 7 as compared to Figure 28 which shows the effects
of a single prf).

Doppler Maps. The relative motions of the transmitter,
receiver, and target dictate the doppler shift at any given
point in X, Y, Z space. A good way to demonstrate this is
to view a plane of interest and see the doppler contours on
that plane. For example, assume the ground plane is the
plane of interest. The doppler shift of any X, Y point
(Z = 0) is a function of the velocity of the ground plane
with respect to the transmitter and receiver platforms.
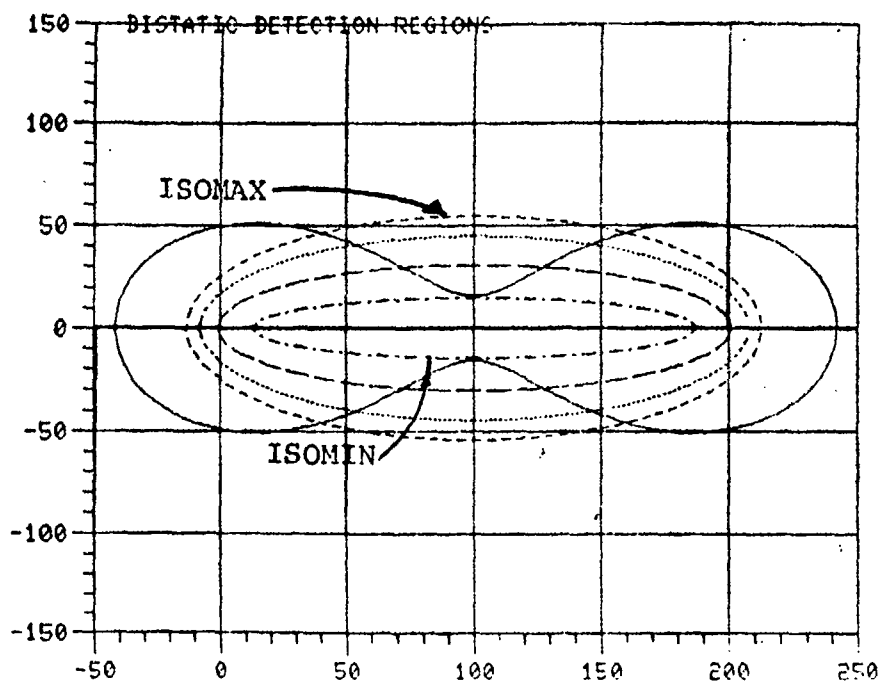
Figure 25   Minimum and Maximum Isoranges
(Increased PRF: 30000 HZ)
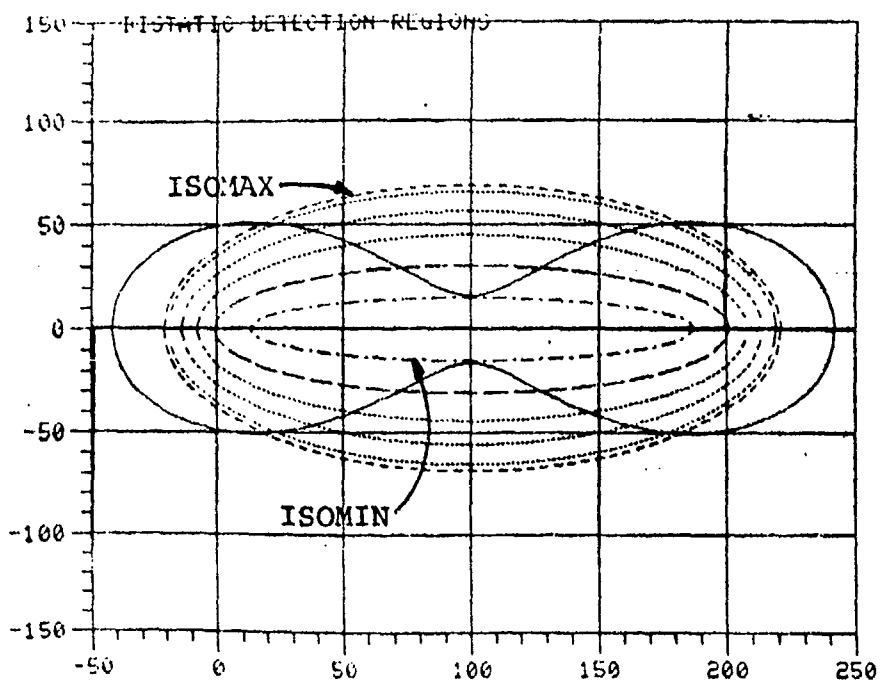
Figure 26   Minimum and Maximum Isoranges
(Decreased PRF: 20000 HZ)

64
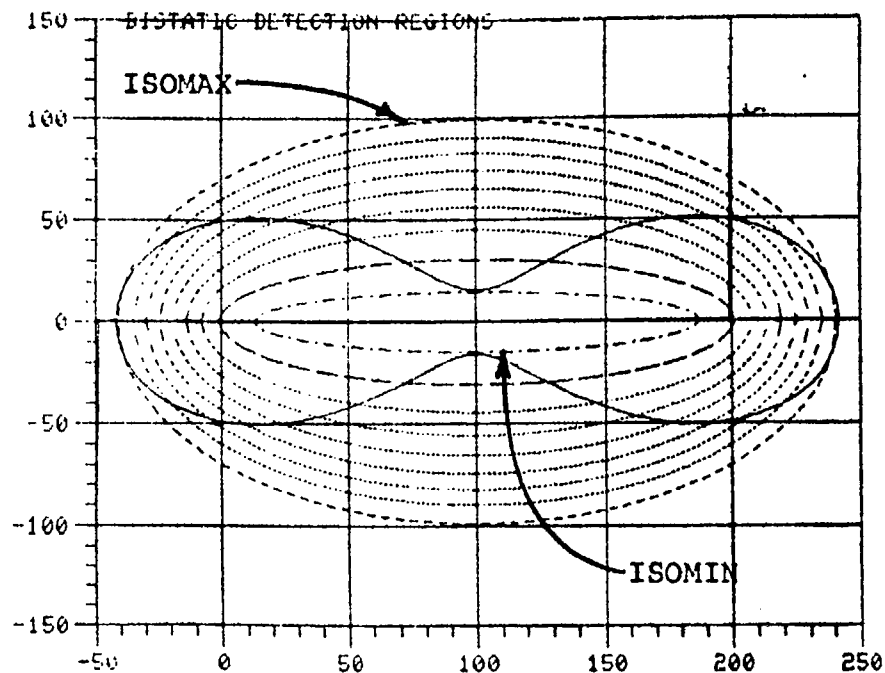
Figure 27 Minimum and Maximum Isoranges
(Multiple PRF: NPRF = 7)
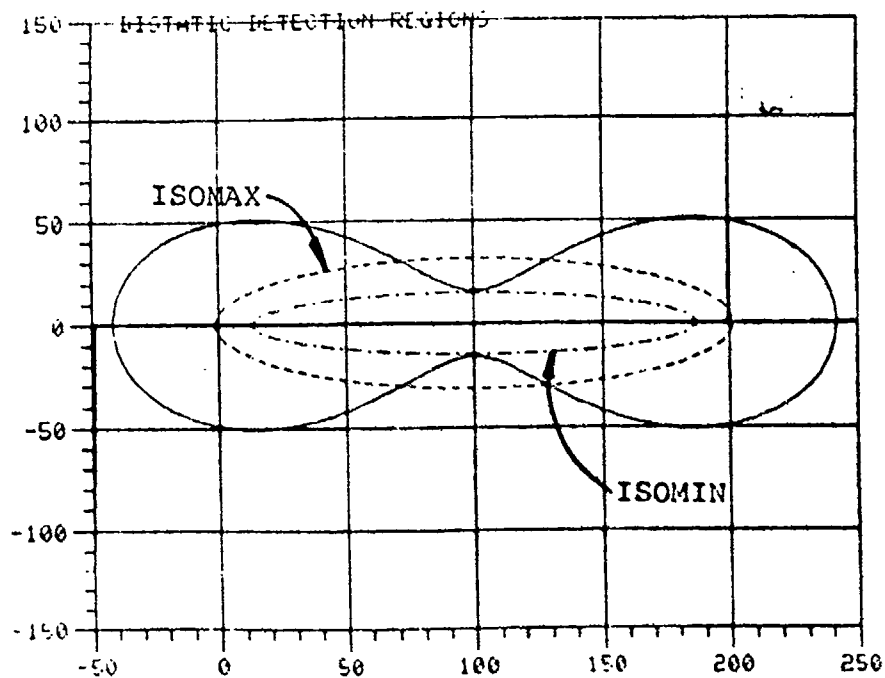
Figure 28 Minimum and Maximum Isoranges
(Single PRF: NPRF = 1)

The doppler map developed by the model is a grid of numbers representing the doppler shift at that particular X, Y point. Because the doppler shift is well behaved, a contour can be drawn by connecting interpolated points on the map. Figure 29 shows the doppler contours for a receiver headed to the left at 600 KPH and a transmitter headed to the right at 600 KPH. The relative separation is 1200 KPH. Figure 30 shows the contours for receiver and transmitter headed left at 600 KPH and remaining a constant distance apart. Figure 31 shows the same pair closing with equal velocity. Figure 32 shows the transmitter receiver pair flying orthogonal (90 degrees with respect to each other). Note the skewing of the doppler contours.
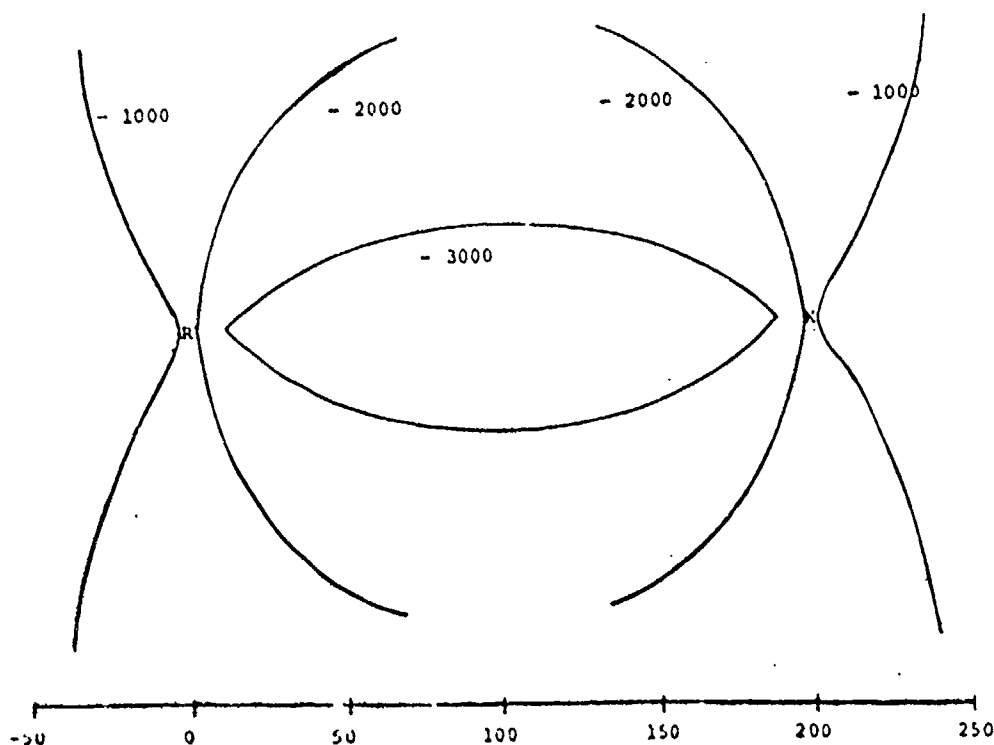
Figure 29   Doppler for Transmitter and Receiver Separating
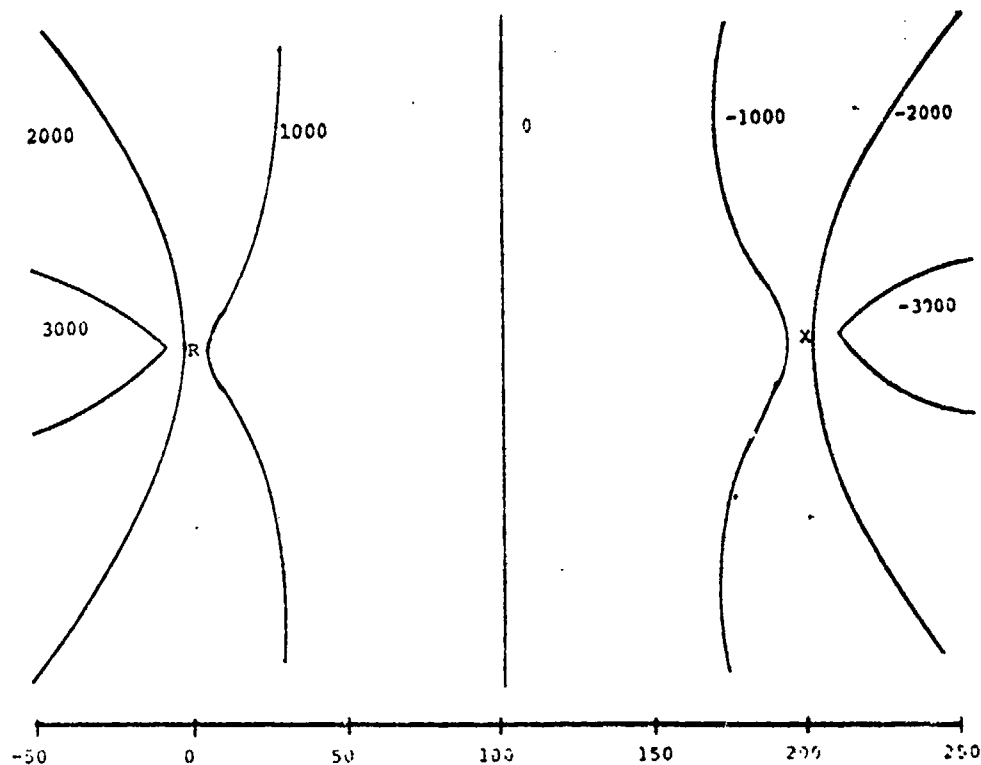
Figure 30 Doppler for Transmitter and Receiver
Constant Separation
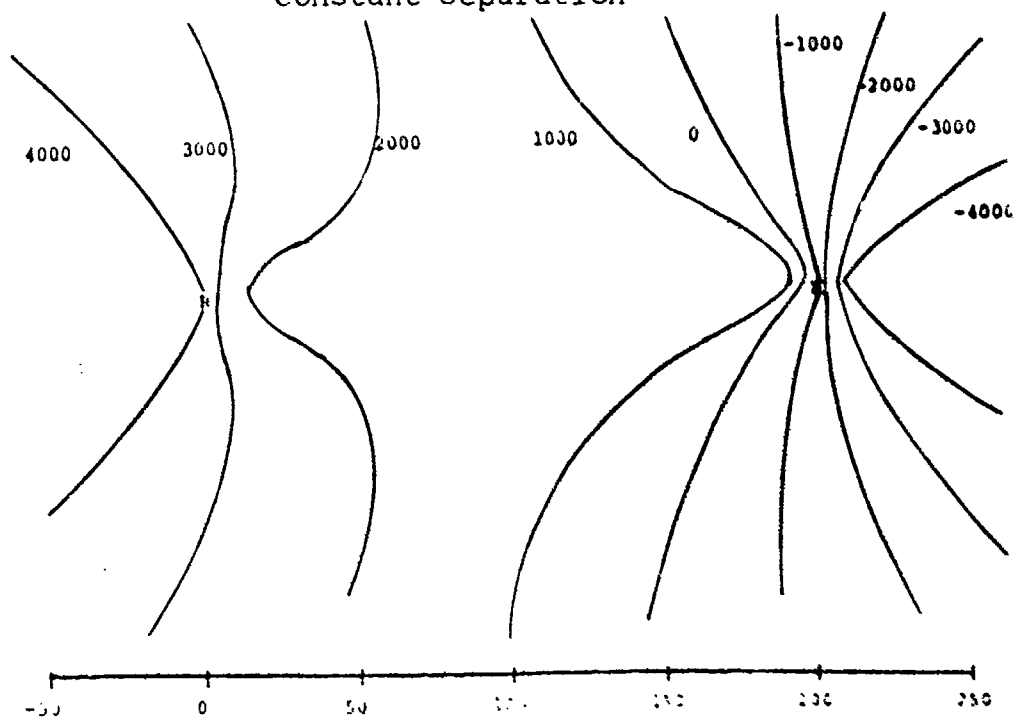
Figure 31 Doppler for Transmitter and Receiver Closing
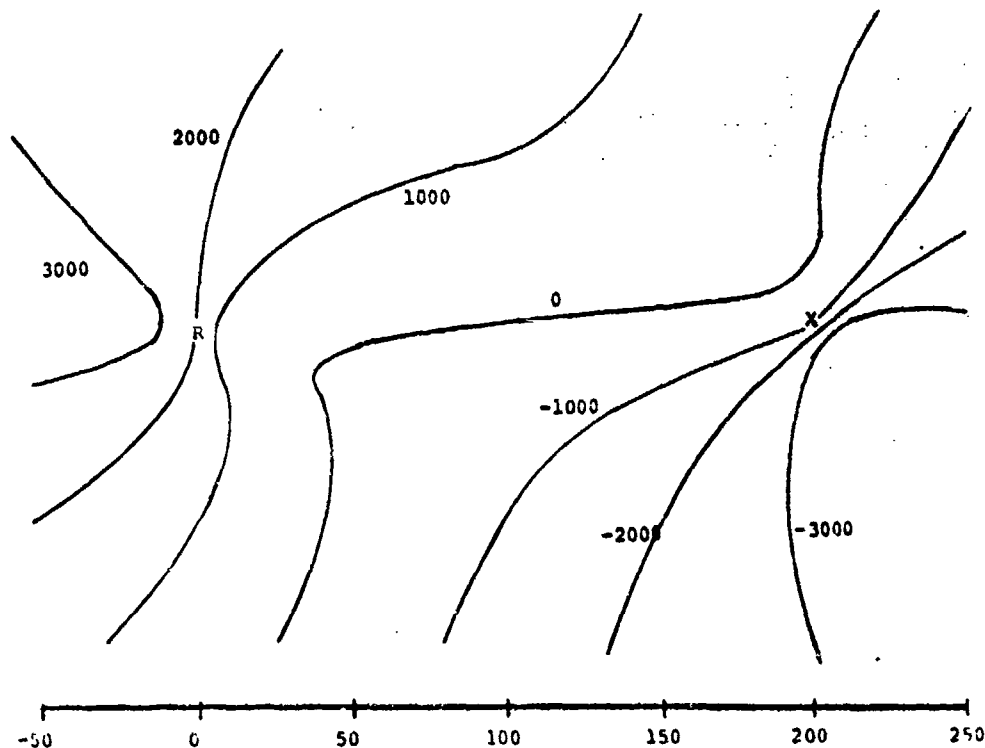
Figure 32   Doppler for Transmitter and Receiver Orthogonal

The transmitter receiver pair will not always fly such regular patterns, nor will they always have the same velocity.   Figure 33 shows the effects of equal velocities but arbitrary headings.   Figure 34 shows the effects of those same headings but with different receiver and transmitter velocities.

For the case of a ground transmitter, the velocity of the transmitter is the same as the ground plane.   The transmitter is at an altitude of 10 meters.   The doppler shift is now only a function of the receiver velocity and heading. Figure 35 shows the doppler map for a receiver separating at 600 KPH.   Figure 36 shows the receiver closing on the transmitter.   Note the change in sign of the contours.
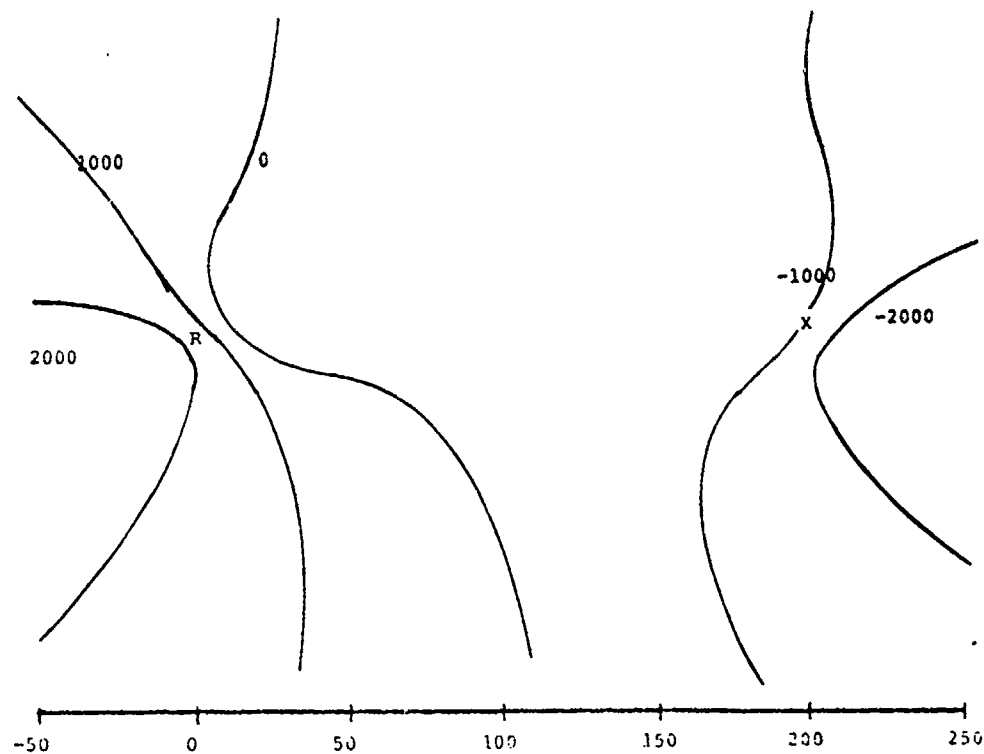
Figure 33 Transmitter and Receiver, Equal Velocities
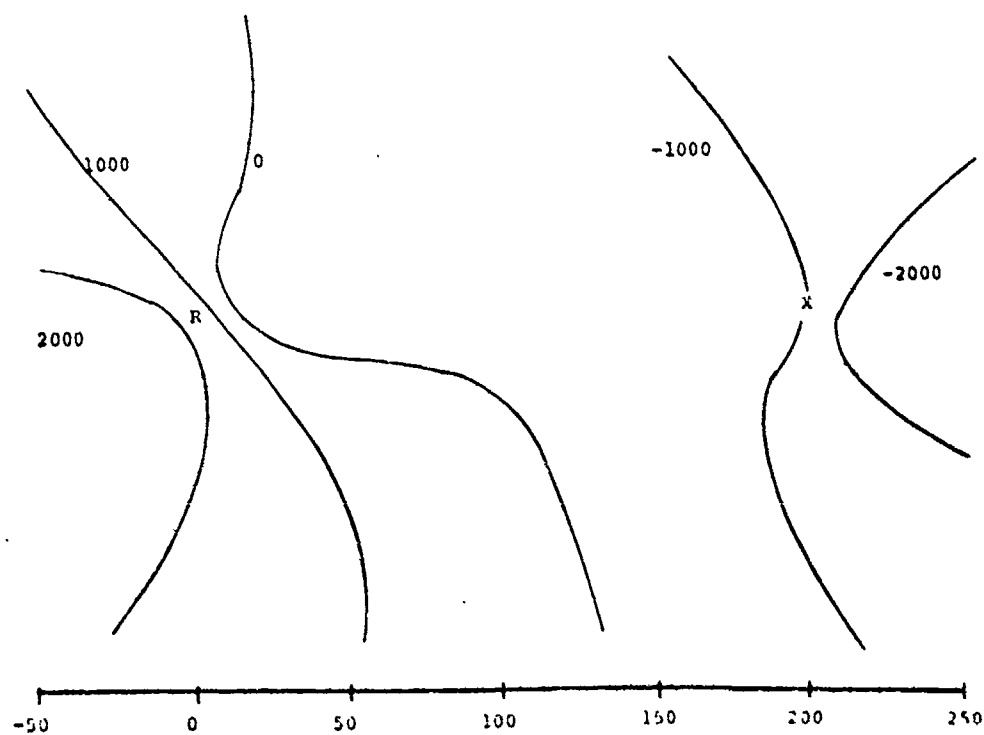
Figure 34 Transmitter and Receiver, Unequal Velocities
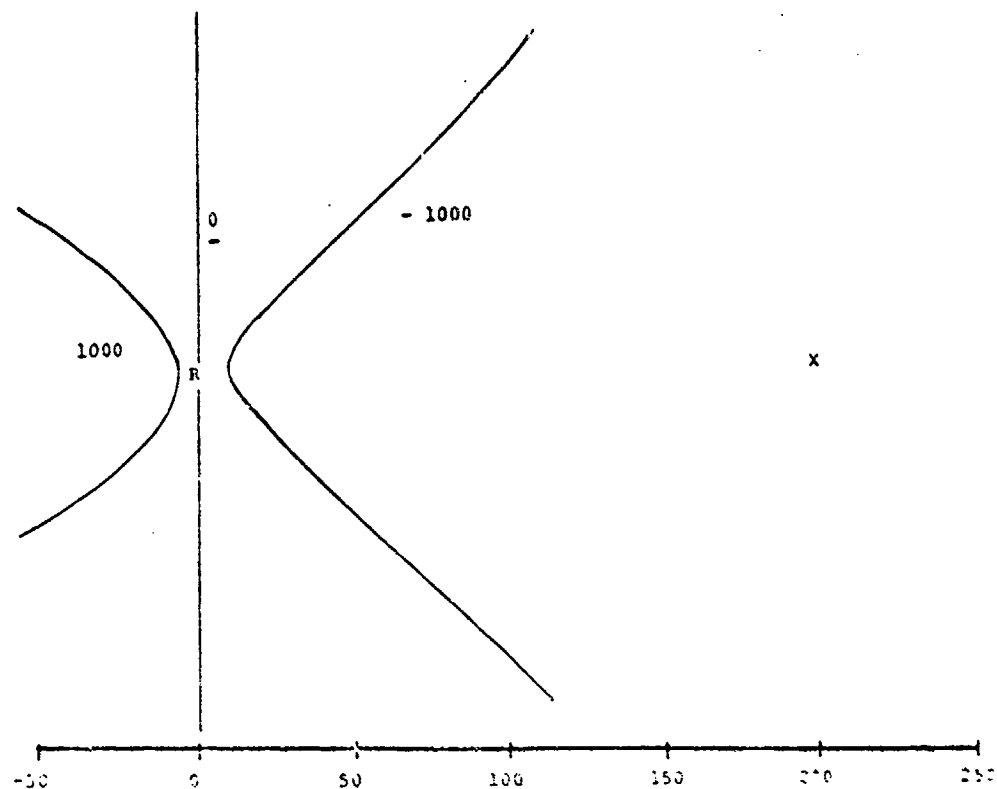
Figure 35 Receiver Separating from Ground Transmitter
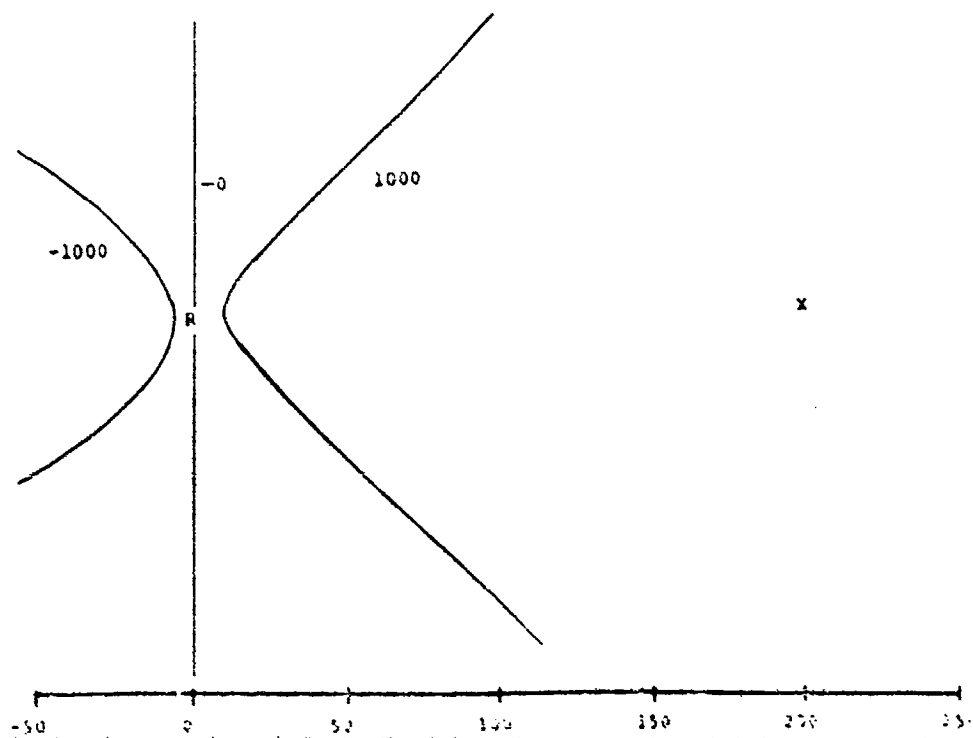
Figure 36 Receiver Closing on Ground Transmitter

Figure 37 shows the contours for a re.... .... flying
orthogonal to the transmitter. Figure 38 d.. ..strates the
skewing of the doppler contours when the receiver is at a
heading 45 degrees with respect to the receiver transmitter
baseline.
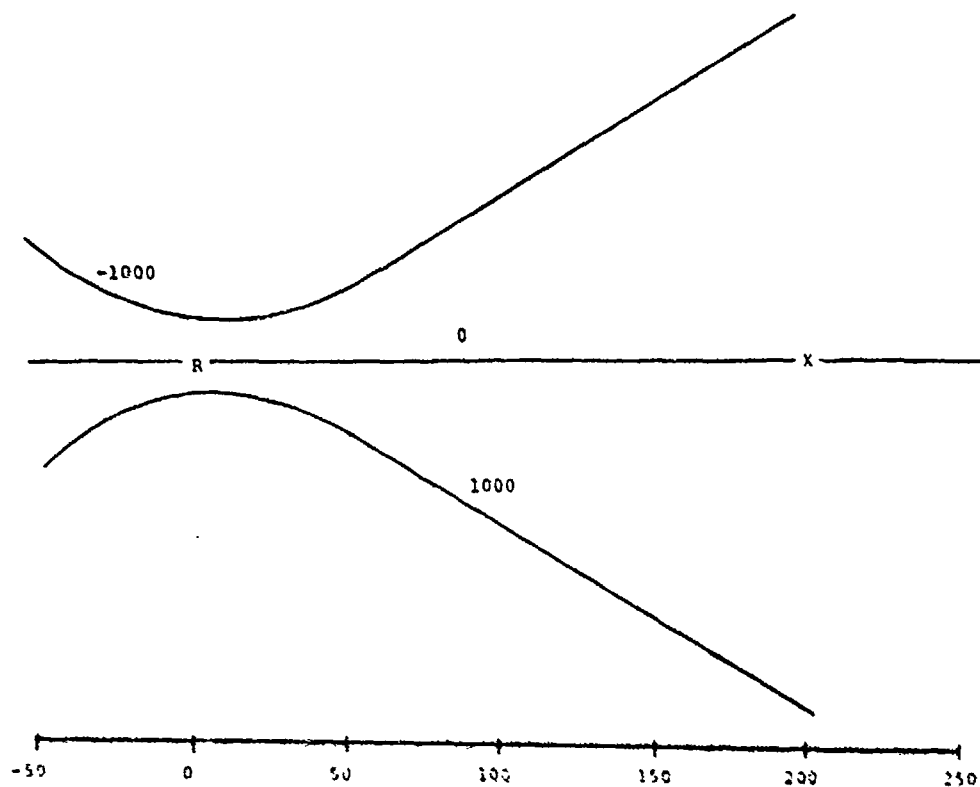
Figure 37 Receiver Orthogonal to Ground Transmitter
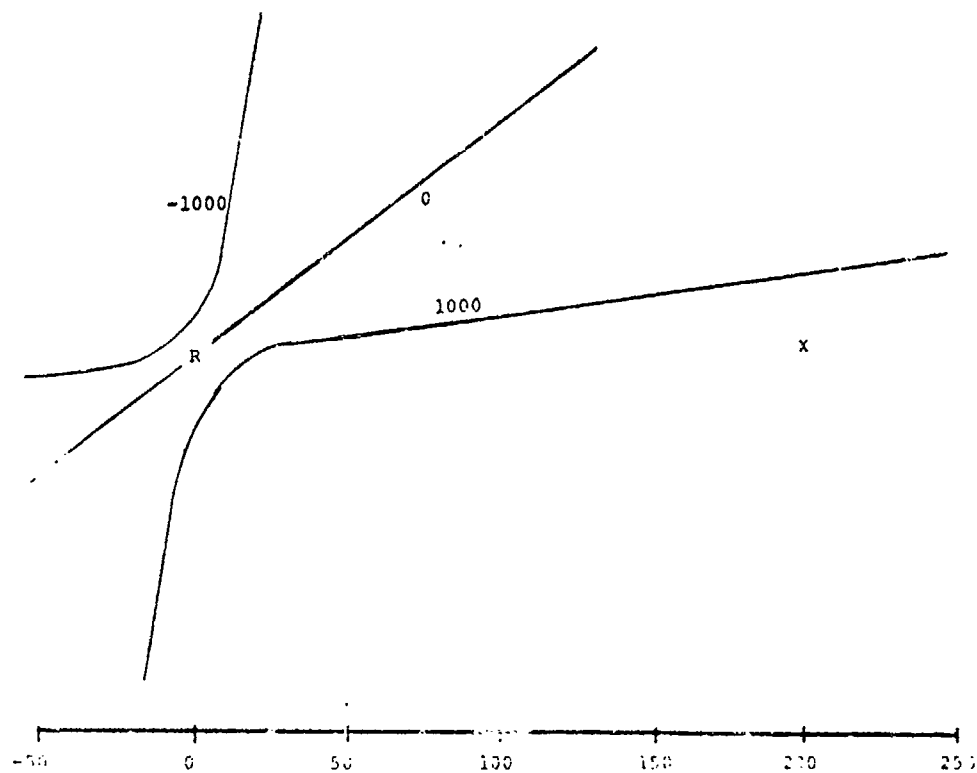
Figure 38   Receiver 45 Degrees from Ground Transmitter

Signal to Clutter Calculations

In Chapter III the Signal to Clutter Ratio (SCR) was developed. The model parameters were varied to demonstrate the effects of changing radar cross section and beam sizes. Figure 39 shows the signal to clutter ratio for the generic waveform. The elevation angle is displayed in 5 degree increments. SCR is shown as a function of azimuth and elevation. Figure 40 demonstrates the change in the SCR when a large target is viewed. Table II lists values for the SCR.

SIGNAL TO CLUTTER RATIO (AZIMUTH ANGLE VS ELEVATION ANGLE)
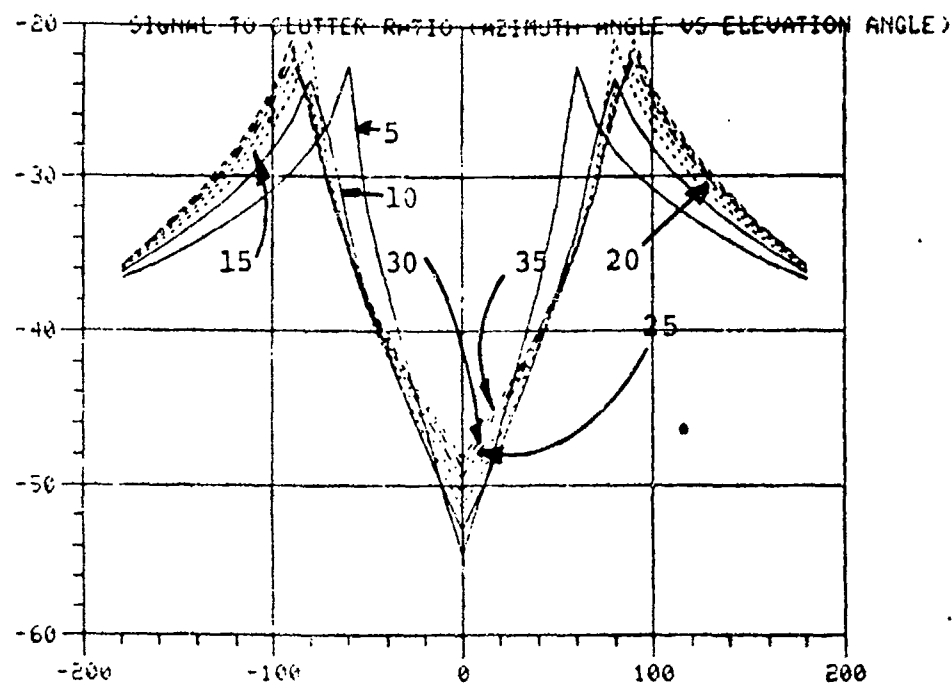
Figure 39   Signal to Clutter Ratio Generic System

SIGNAL TO CLUTTER RATIO (AZIMUTH ANGLE VS ELEVATION ANGLE)
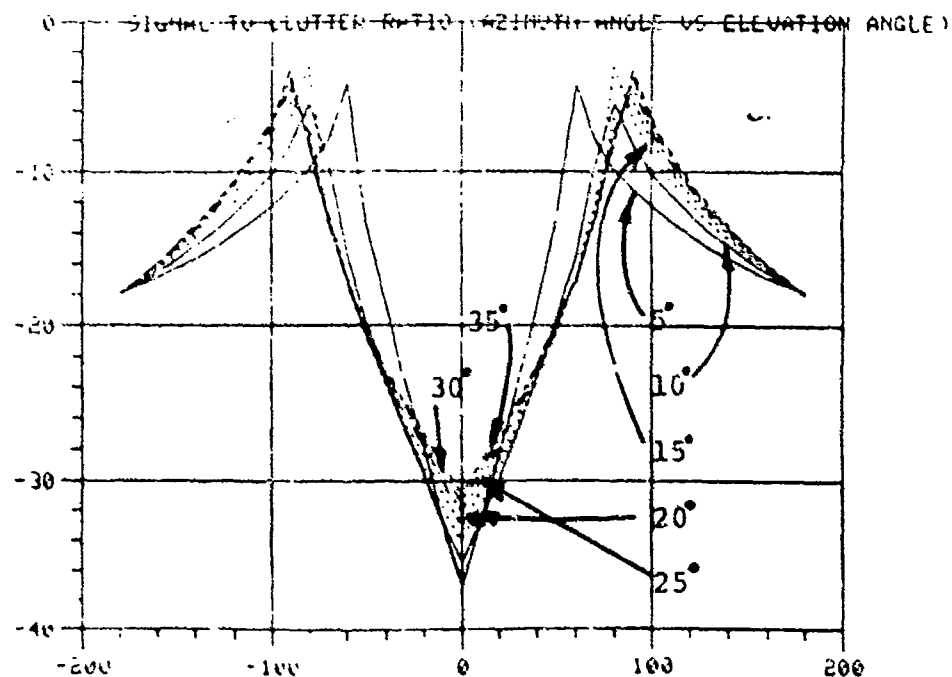
Figure 40   Signal to Clutter Ratio, Target RCS = 100 Sq M.

73

TABLE II

Signal to Clutter Values Generic Waveform

<						Azimuth Angle						>	
-180	-150	-120	-90	-60	-30	0	30	60	90	120	150	180	El
-37.	-35.	-33.	-30.	-23.	-42.	-55.	-42.	-23.	-30.	-33.	-35.	-37.	5.
-36.	-34.	-31.	-26.	-33.	-45.	-53.	-45.	-33.	-26.	-31.	-34.	-36.	10.
-36.	-33.	-30.	-24.	-35.	-44.	-51.	-44.	-35.	-24.	-30.	-33.	-36.	15.
-36.	-33.	-29.	-23.	-35.	-44.	-50.	-44.	-35.	-23.	-29.	-33.	-36.	20.
-36.	-33.	-29.	-22.	-35.	-43.	-50.	-43.	-35.	-22.	-29.	-33.	-36.	25.
-36.	-33.	-28.	-22.	-35.	-43.	-49.	-43.	-35.	-22.	-28.	-33.	-36.	30.
-36.	-32.	-28.	-21.	-34.	-42.	-48.	-42.	-34.	-21.	-28.	-32.	-36.	35.

The use of a ground transmitter changes the SCR slightly. Figure 41 shows the SCR for a small target, ground transmitter combination. Figure 42 shows the SCR for a large target. Table III lists the values for the generic waveform and a ground transmitter.
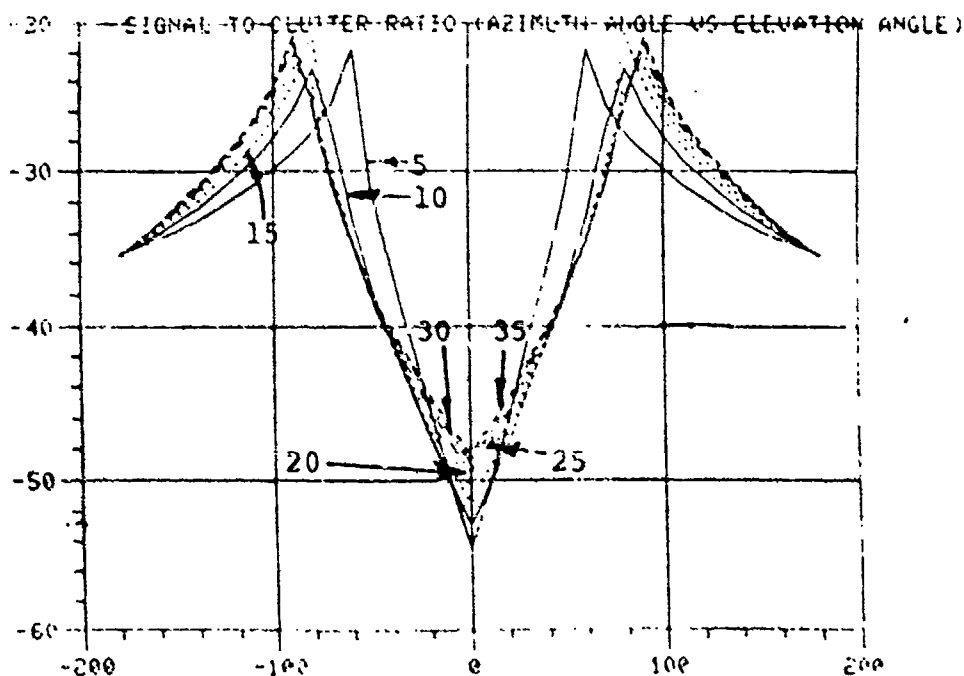
Figure 41 SCR: Ground Transmitter, Small Target

74
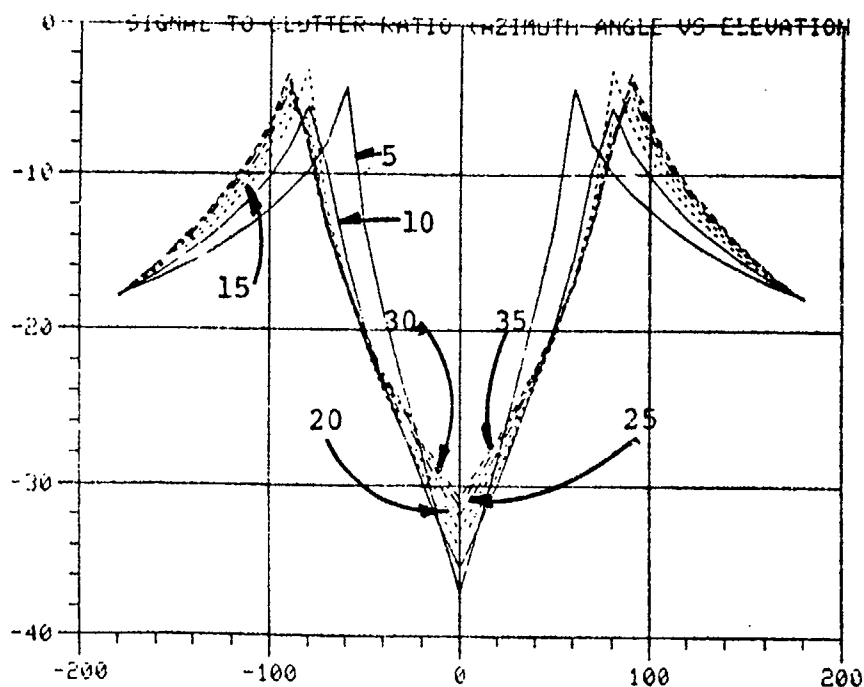
Figure 42   SCR: Ground Transmitter, Target RCS =100 Sq. M.

TABLE III

SCR Values Generic Waveform, Ground Transmitter

<						Azimith Angle						>	
-180	-150	-120	-90	-60	-30	0	30	60	90	120	150	180	El
-37.	-35.	-33.	-30.	-23.	-42.	-55.	-42.	-23.	-30.	-33.	-35.	-37.	5.
-36.	-34.	-31.	-26.	-33.	-45.	-53.	-45.	-33.	-26.	-31.	-34.	-36.	10.
-36.	-33.	-30.	-24.	-35.	-44.	-51.	-44.	-35.	-24.	-30.	-33.	-36.	15.
-36.	-33.	-29.	-23.	-35.	-44.	-50.	-44.	-35.	-23.	-29.	-33.	-36.	20.
-36.	-33.	-29.	-22.	-35.	-43.	-50.	-43.	-35.	-22.	-29.	-33.	-36.	25.
-36.	-33.	-28.	-22.	-35.	-43.	-49.	-43.	-35.	-22.	-28.	-33.	-36.	30.
-36.	-32.	-28.	-21.	-34.	-42.	-48.	-42.	-34.	-21.	-28.	-32.	-36.	35.

Doppler Spread of the Clutter Cell

The doppler spread of the clutter cell is a function of
the beam shape and the platform velocities. The clutter cell
doppler spread for a separating receiver transmitter pair

is shown in Figure 43. The doppler spread is shown for elevation look angles of 5, 10, 15, 20, 25, 30, and 35 degrees. Note that the greater the depression angle, the less the doppler spread.

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)
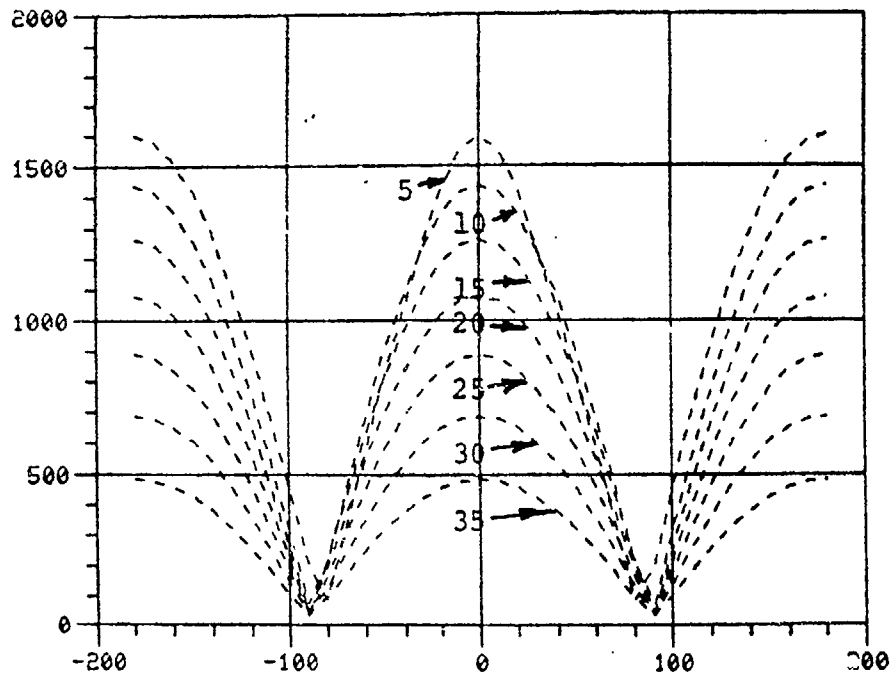
Figure 43   Doppler Spread Generic, Separating

Figure 44 shows the doppler spread for a synchronous flight pair where the transmitter and receiver are at a constant separation distance. Figure 45 shows the doppler spread for a transmitter receiver pair closing.

Figure 44   Doppler Spread, Constant Separation

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)
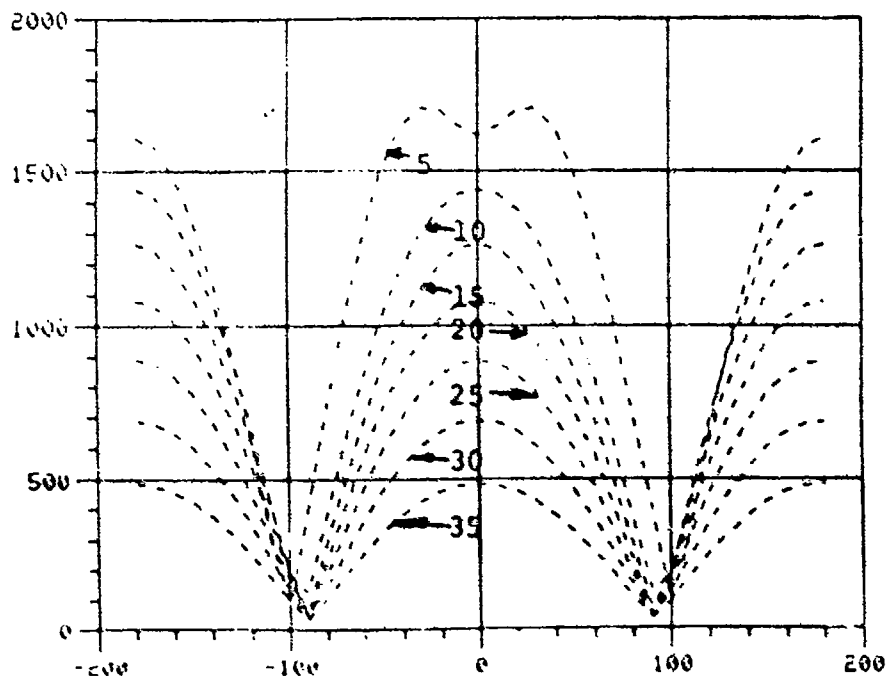
Figure 45   Doppler Spread, Closing

77

The doppler spread varies with the flight path orientation. If the transmitter and receiver are flying orthogonal, the doppler spread skews as shown in Figure 46. Figure 47 shows the doppler spread for a transmitter receiver pair flying arbitrary headings of 53 degrees and 315 degrees respectively. Figure 48 shows the doppler spread for transmitter and receiver having the arbitrary headings and different velocities.

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)
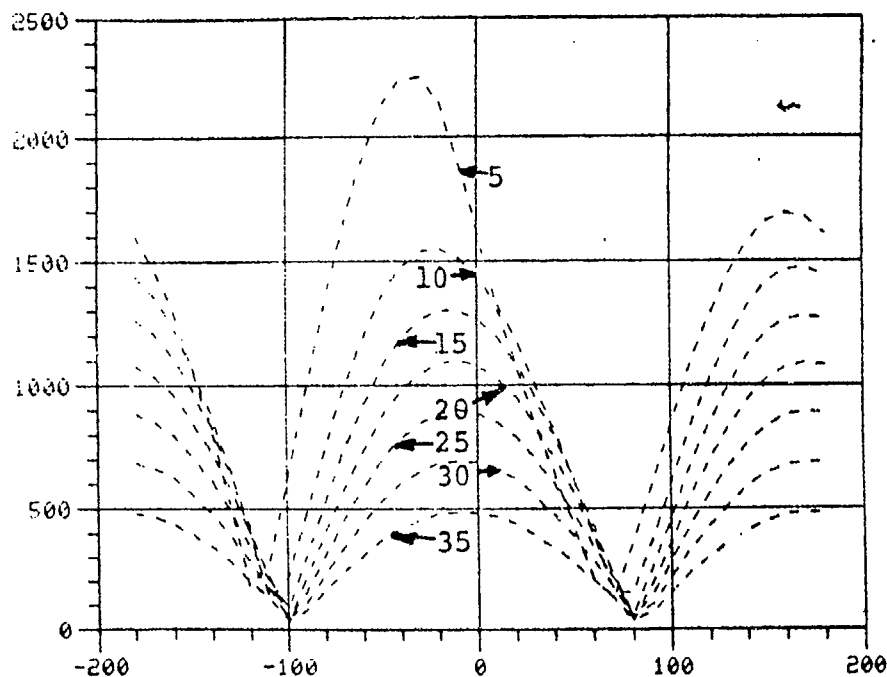
Figure 46   Doppler Spread, Orthogonal

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)
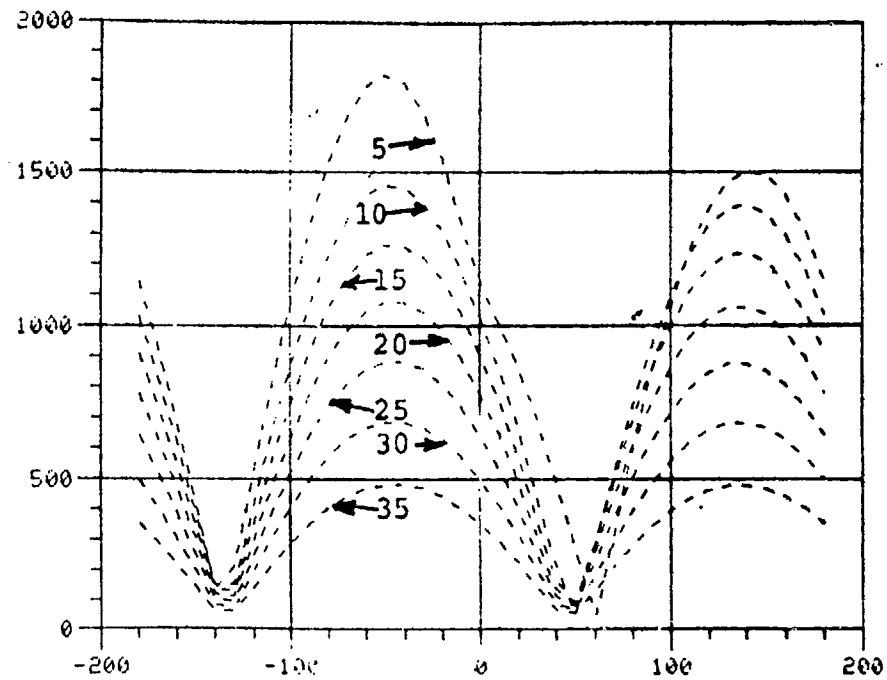
Figure 47 Doppler Spread, Arbitrary, Equal Velocities

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)
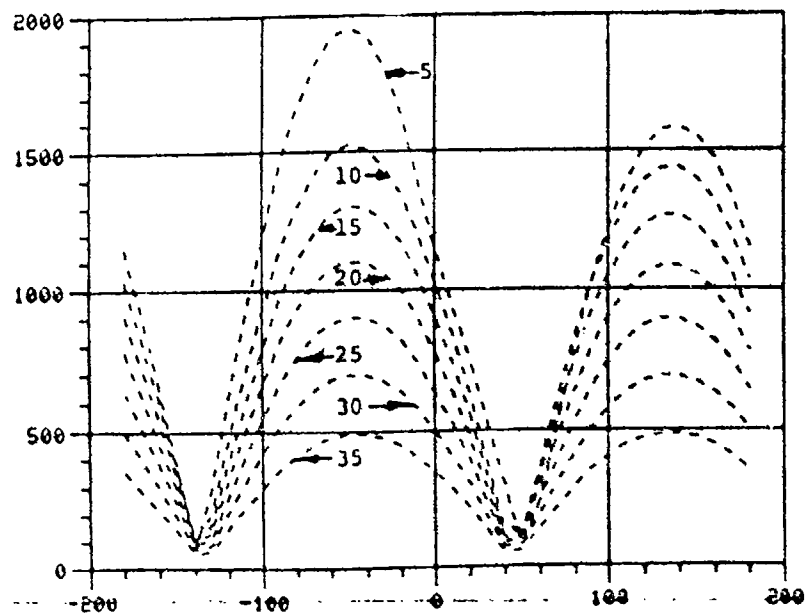
Figure 48 Doppler Spread, Arbitrary, Unequal Velocities

The doppler spread for a ground transmitter to airborne receiver is dependent upon the beam shapes of both platforms but only the velocity and heading of the receiver. Therefore, the doppler spread of the air to ground system is better behaved. Figure 49 shows the doppler spread for a closing receiver while Figure 50 shows the doppler spread for a separating pair. Note that a closing and separating system have the same spread. It should be realized that the doppler spread is the same but the doppler shift of the clutter cell is not at the same place in the frequency spectrum. If the receiver flys orthogonal to the transmitter, the doppler spread of the beam shifts as shown in Figure 51.

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)
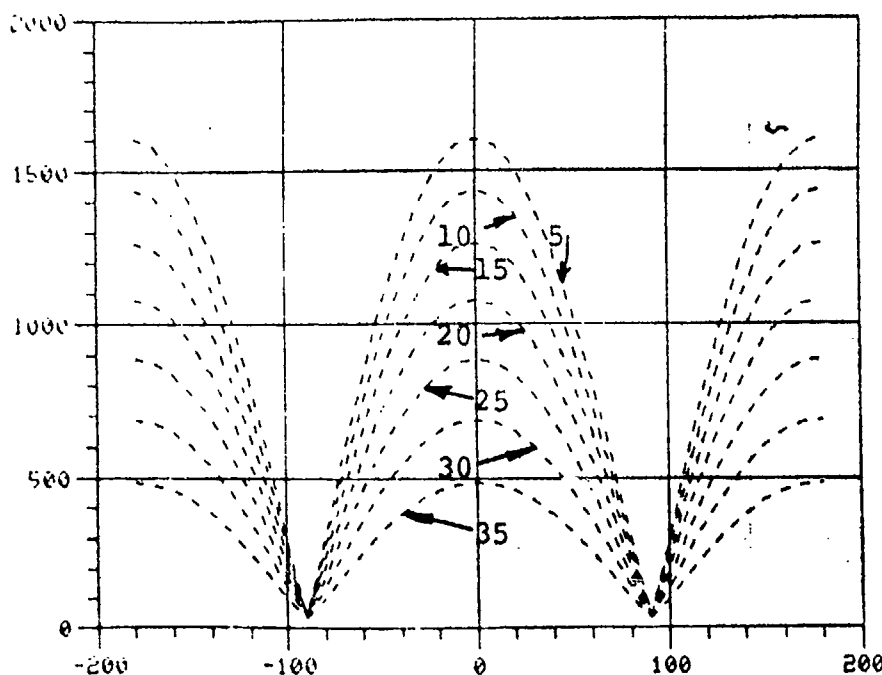
Figure 49 Doppler Spread, Air to Ground, Closing
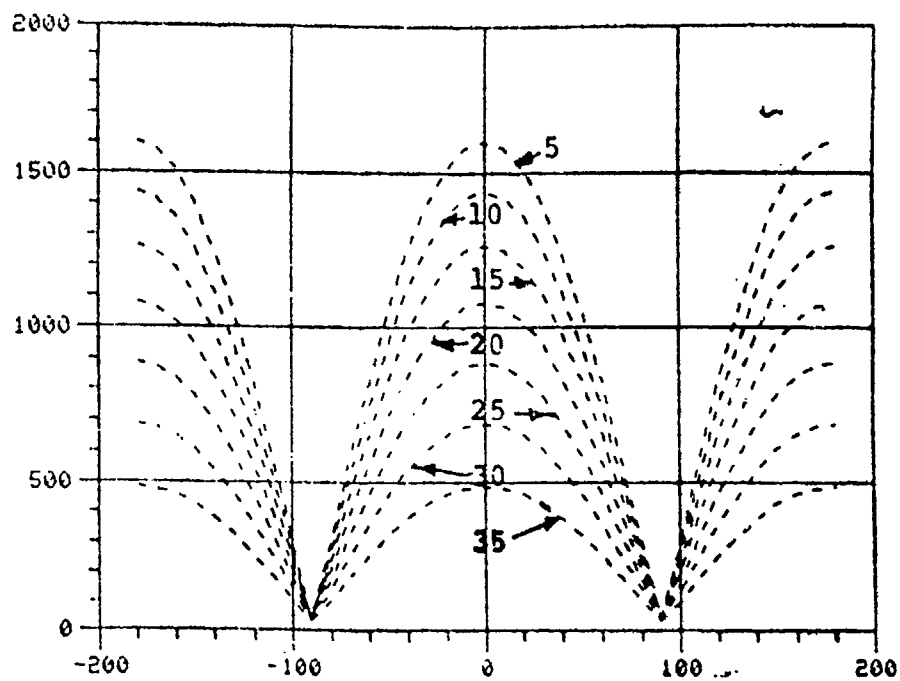
Figure 50   Doppler Spread, Air to Ground, Separating

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)
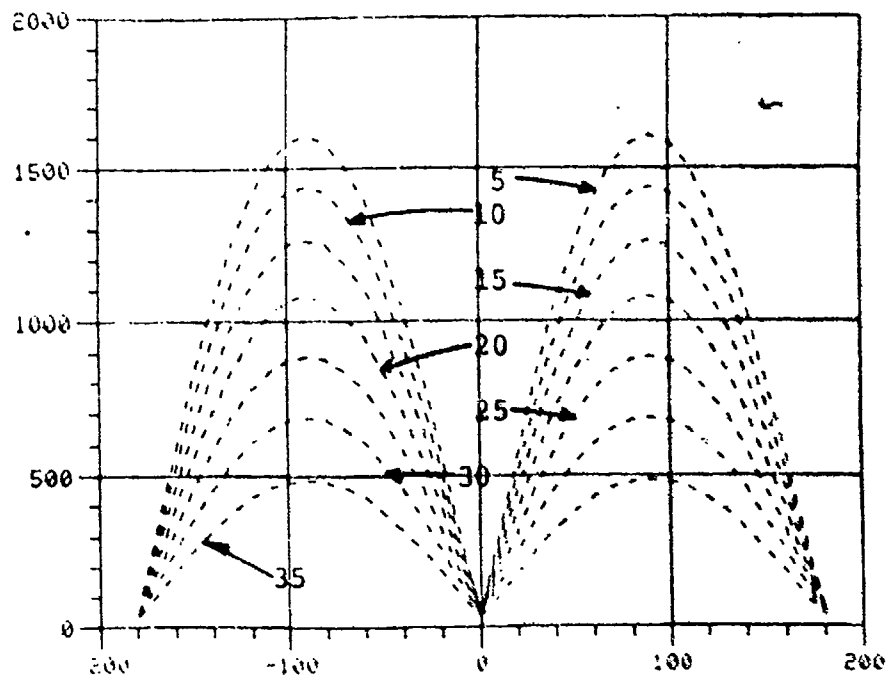
Figure 51   Doppler Spread, Air to Ground, Orthogonal

The air to ground system doppler spread shifts with
respect to the heading of the receiver. Figure 52 shows the
shift for a heading of 315 degrees with respect to the trans-
mitter receiver baseline while Figure 53 shows the doppler
shift for a heading of 243 degrees.

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE US ELEVATION ANGLE)
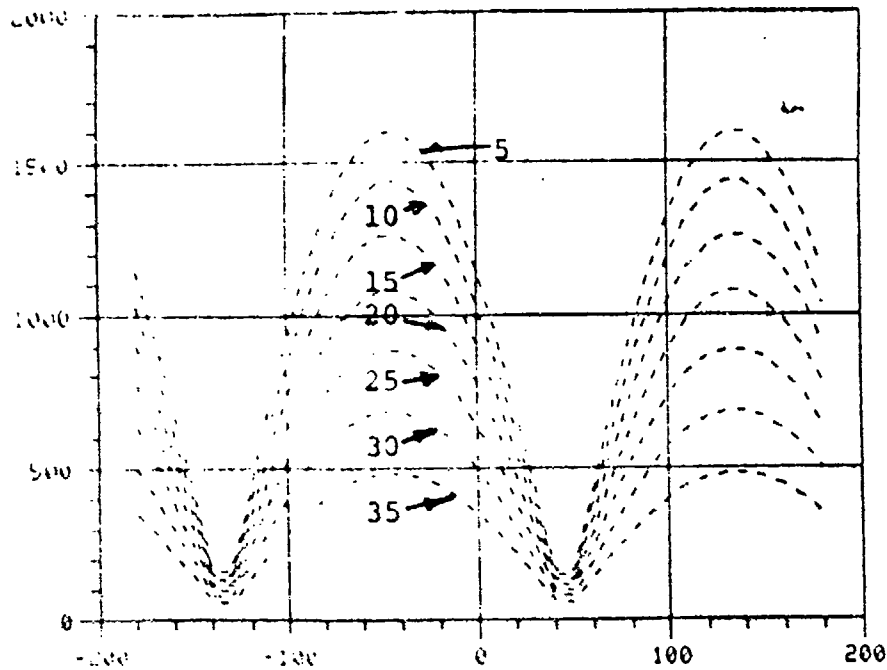
Figure 52   Doppler Spread, Air to Ground,
315 Degree Heading

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)
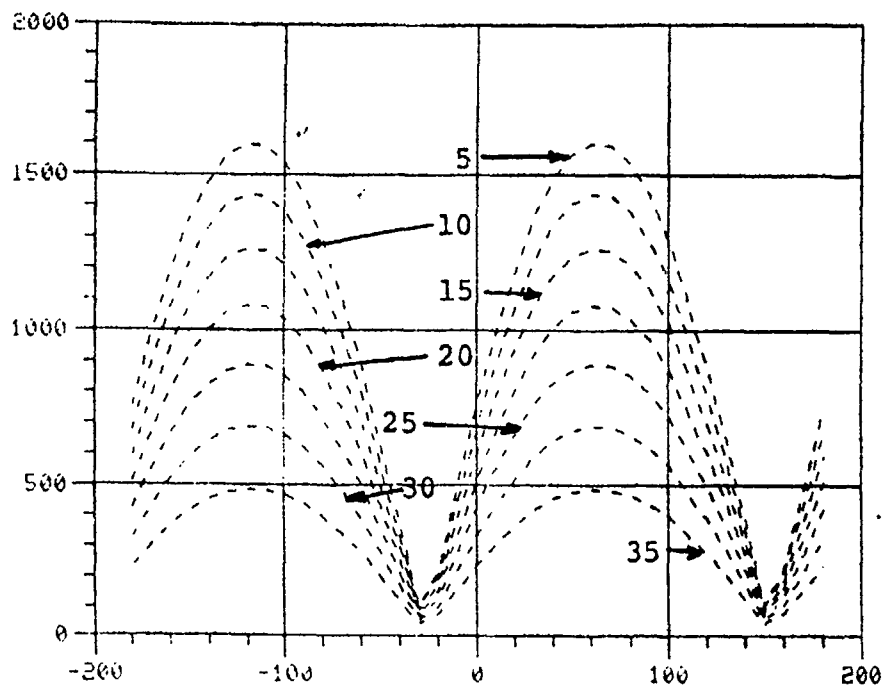
Figure 53   Doppler Spread, Air to Ground,
243 Degree Heading

The doppler spread of the beam is best understood by
comparing the several relative velocities.   Table IV gives
values for several bistatic doppler shifts.   Because the
shift can be either positive or negative, the potential tar-
get could be closing or receding within the clutter spread.
Obviously, minimizing the spread of the beam improves the
visibility of slow moving targets.   Table IV values are for
a 3 Gigahertz carrier.

TABLE IV

Doppler Shift Versus Velocity

Doppler Frequency Shift (Hz)	Kilometers Per Hour	Miles Per Hour	Nautical Miles Per Hour
2000	720	446	389
1500	540	335	292
1000	360	223	194
500	180	112	97
269	97	60	52

Sample Scenario

Suppose that the doppler spread and the bistatic detection regions for a possible surveillance scenario are of interest. Assume two similar radar platform headed in opposite directions, passing side by side separated by 175 kilometers when orthogonal as shown in Figure 54.
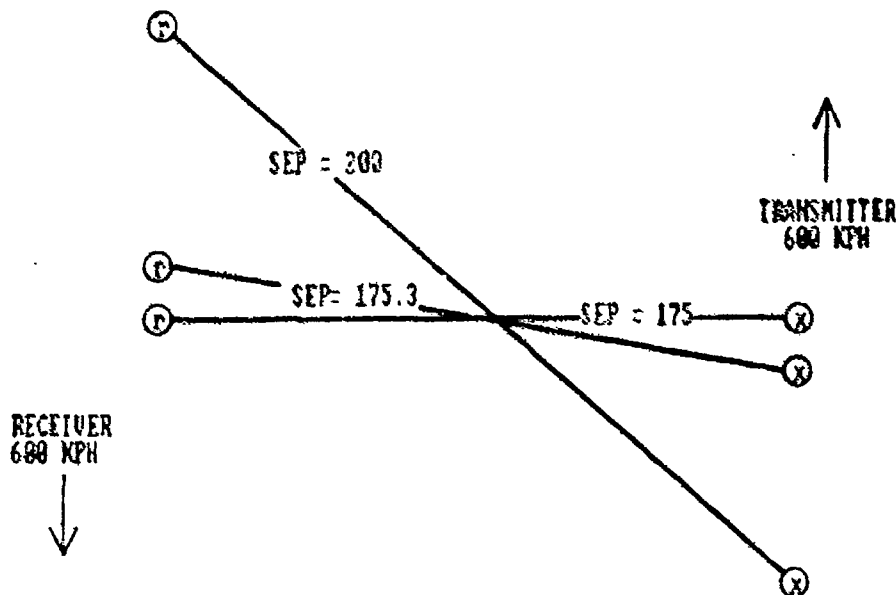
Figure 54 Possible Air to Air Scenario

Figure 55 is a composite of three bistatic detection region graphs to show the area of coverage from the time the base line is 200 Kilometers until the platforms are at right angles separated by 175 Kilometers. As the platforms separate, a mirror image (with respect to the graph base line) of the detection region is traced out. The time between curve one and curve two is 261 seconds. The time between curve two and curve three is 30 seconds. Note changes in both areas which are visible and blind to the receiver.
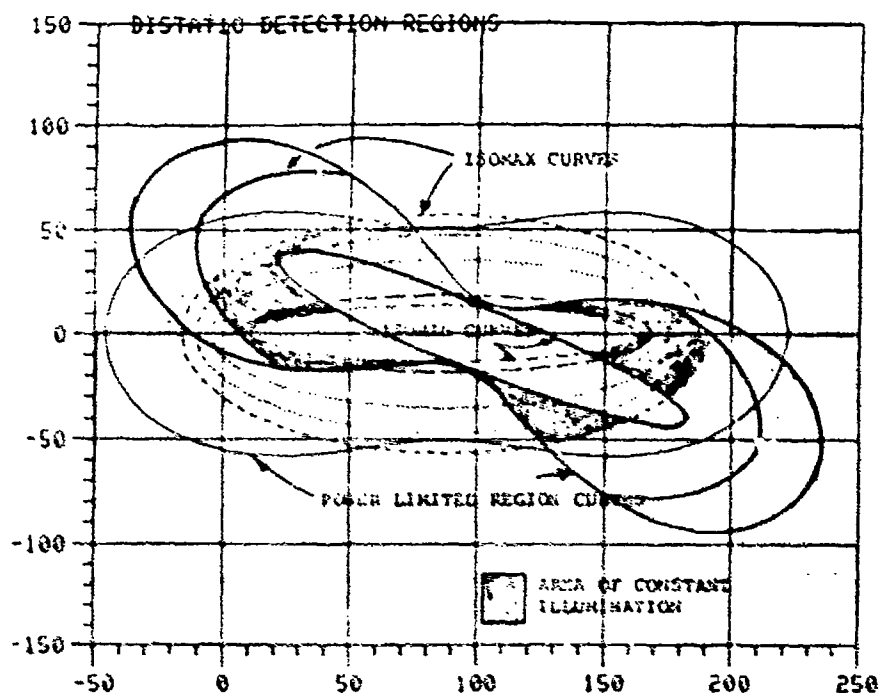
Figure 55   Change in Bistatic Detection Regions

Just as the detection regions change, the doppler spread of the clutter cell changes. Figure 56 shows the clutter cell doppler spread for initial acquisition at 200

kilometers. Figure 57 shows the change in the doppler spread
as the transmitter receiver pair approach their minimum
separation, while Figure 58 shows the doppler spread during
the moment when the pair are orthogonal. Figure 59 shows the
doppler spread as the transmitter and receiver platforms
separate. Note in particular the doppler shift for the var-
ious angles of beam elevation and the shift in the magni-
tude of the beam spread.

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)

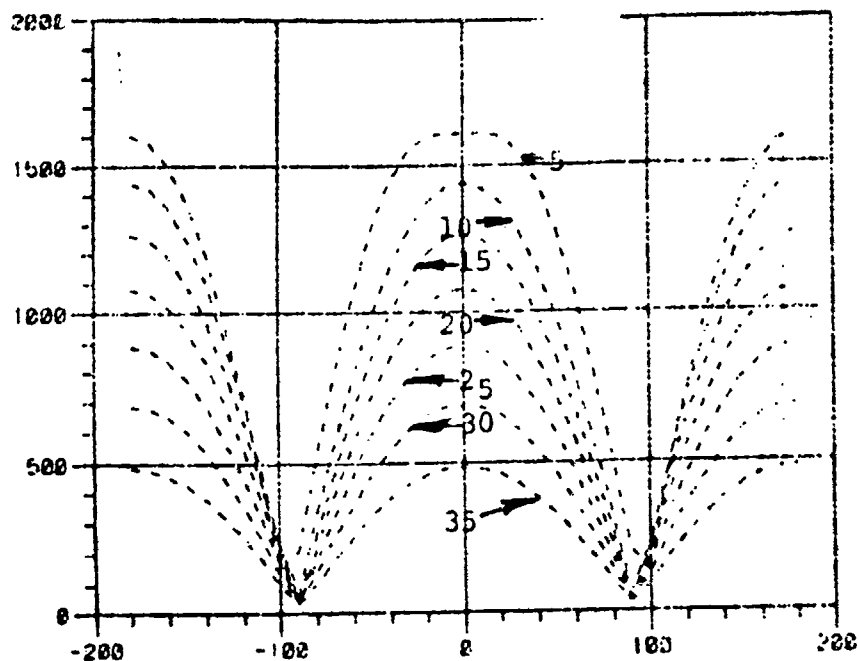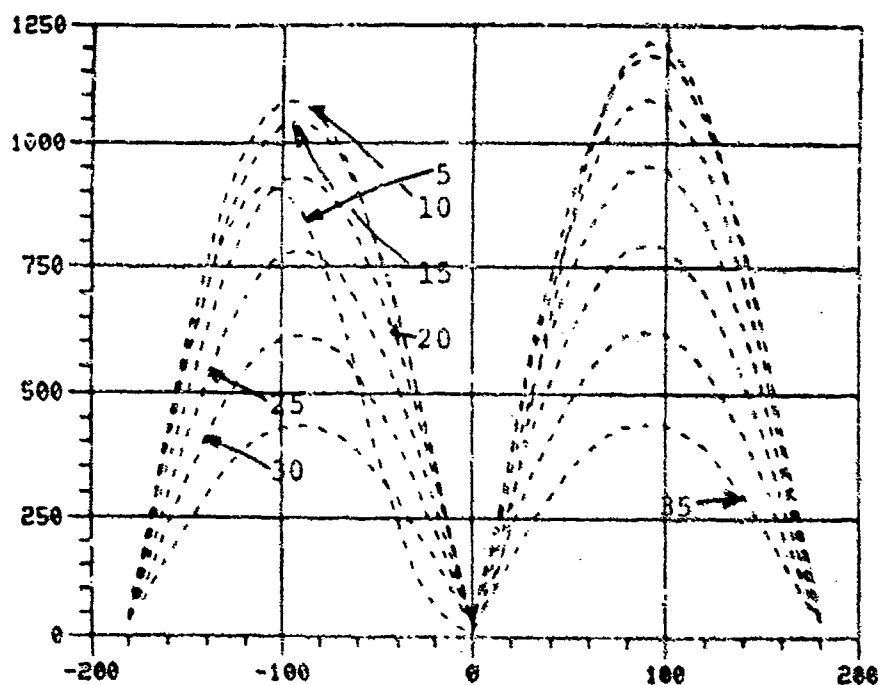Figure 56   Doppler Spread, Closing
            (Separation = 200 KM)
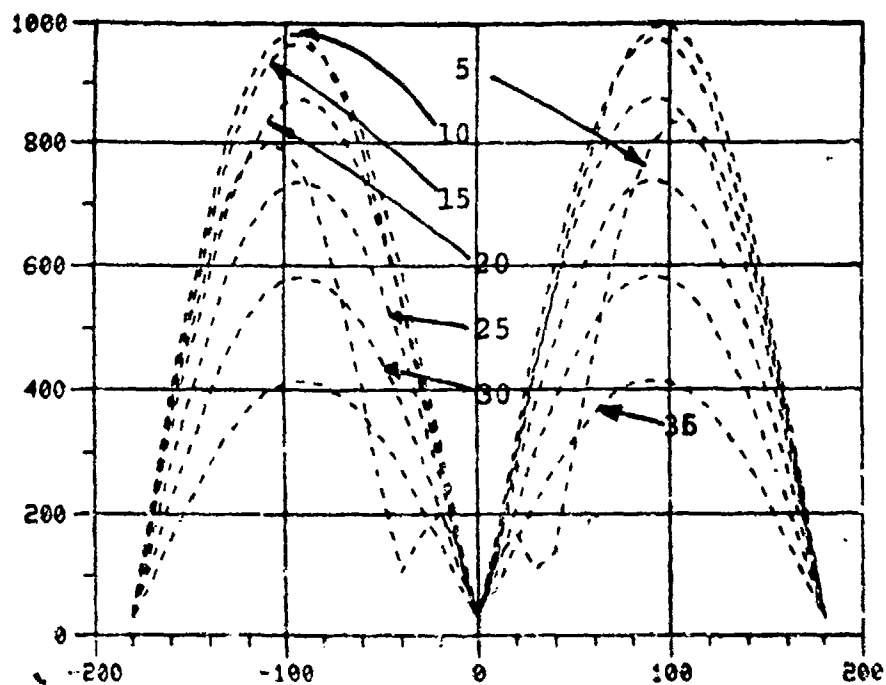
Figure 57   Doppler Spread, Closing
(Separation = 175.3 KM)

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)
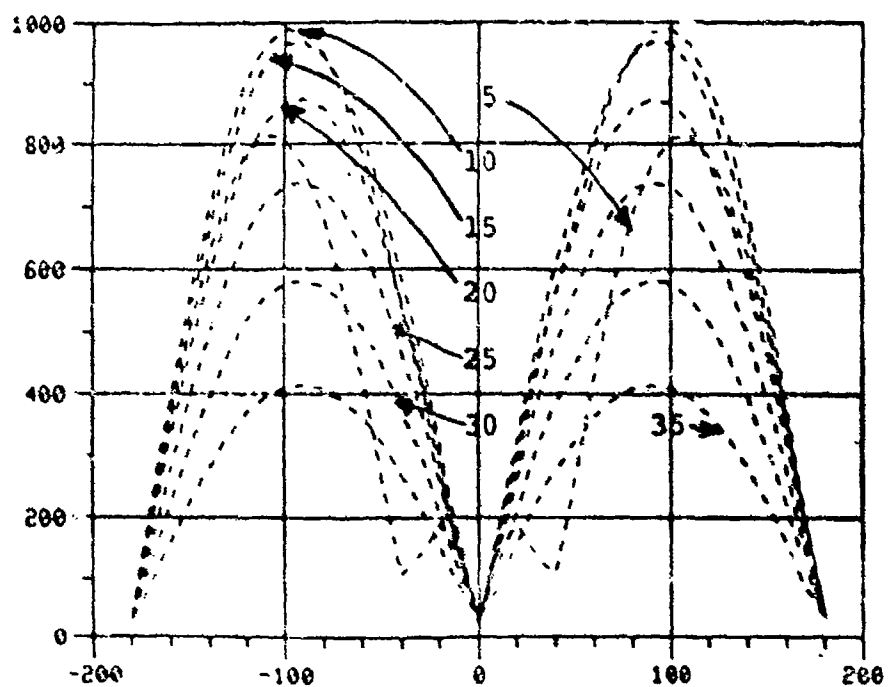
Figure 58   Doppler Spread, Receding
(Separation = 175.0 KM)

87

DOPPLER SPREAD OF BEAM (AZIMUTH ANGLE VS ELEVATION ANGLE)
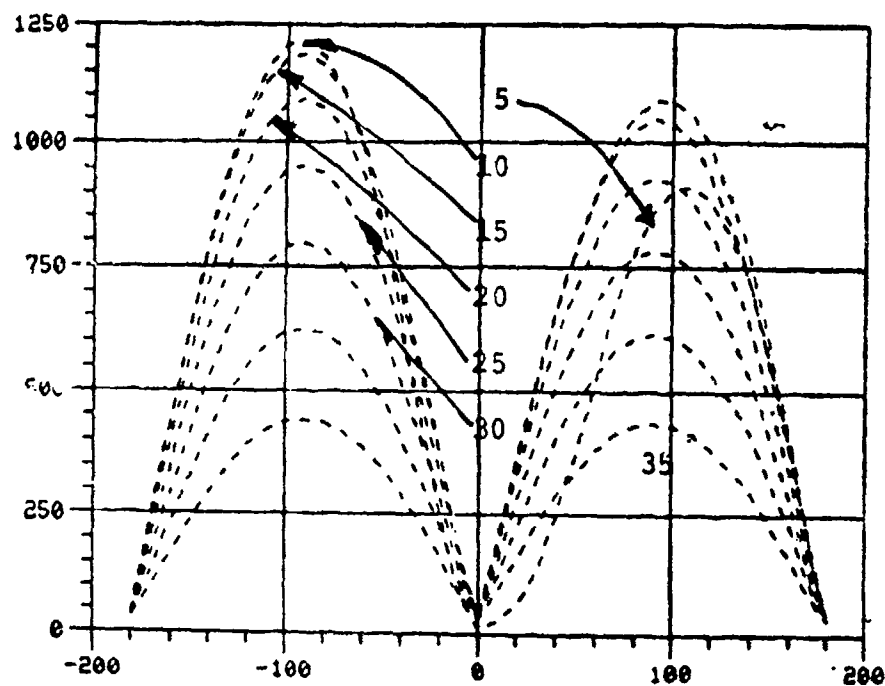
Figure 59   Doppler Spread, Receding
            (Separation = 200 KM)

The sample scenario shows the shift in the detection regions and the shift in the doppler spread of the clutter cell. A passive receiver must be capable of dynamically adjusting parameters in order to maximize the possible information available at its antenna.

V. Summary, Conclusions and Recommendations

Summary

The bistatic radar problem is composed of many variables. The model developed demonstrates the need for understanding the effects of these variables on the detection regions. The model demonstrates the ability to predict the signal to clutter ratios and doppler effect for particular beam shapes and system configurations. The system and its viewing area is more complex and limited when compared to a monostatic radar system. The bistatic system is faced with a blind zone which is controlled by the waveform parameters. Chapter IV examples demonstrated the effects of varying the parameters such as pulse duration and pulse repetition frequency. Varying other system parameters such as the antenna gain and beam shape have similar effects on the Ovals of Cassini.

The figures of merit for clutter and doppler spread of the beam are predictable, and therefore usable in real time processing. The doppler spread and SCR functions are well behaved and will allow a surveillance receiver to continually update the waveform processing portion of the receiver. Continuous updates would allow for improved performance and sub-clutter visibility by having a dynamically varying clutter notch filter.

The means for exploiting a bistatic radar system are apparent. This system is most vulnerable along the

89

transmitter receiver baseline. The blind zone is limited
by waveform and doppler spread. Additionally, the system
needs to be able to have rapid synchronization and acquisi-
tion of the transmitter waveform. Changing the waveform
will disrupt the receiver surveillance until the system can
be resynchronized. Any parameter which maximizes the viewing
area of the receiver platform is a prime candidate for change
if the transmitter wishes to deny or decrease the viewing
area of the receiver. Specifically, increasing the pulse
width or the prf and decreasing the prf multiple will cause
a drastic change in the receivers viewing area. In fact,
these changes could effectively blind the receiver.

Conclusions

Choice of a good host receiver pair waveform is essen-
tial in maximizing the bistatic viewing area. For example,
it was shown in Chapter IV that a low prf, multiple prf,
short pulse duration waveform provides much greater viewing
area. Examination of the equations of interest lead to the
conclusion that to maximize the viewing area, the system
must strive to maximize: power, gain of the antennas and
the bistatic radar cross section of the target. The system
should also minimize: the receiver bandwidth, the transmitted
wave length (maximize transmitter frequency), system losses,
and receiver front end temperature.

The choice of maximizing or minimizing a particular
parameter may not be within the capability of the receiver

if the transmitter is non-cooperative. Likewise, the receiver can do nothing to change the radar cross section of a target. The practical step is to maximize those parameters which are within the control of the receiver. If the transmitter and receiver are cooperative, the transmitter must generate a waveform which is beneficial to the receiver. If the transmitter is non-cooperative, the receiver should look to acquire only those waveforms which provide adequate coverage. In the event of an inadequate transmitter receiver pair waveform, the receiver would have to generate its own waveform and become a monostatic platform, or be prepared to cancel its surveillance activities.

Recommendations

1. The Bistatic Model should be extended to include:

    - The Curved Earth Model

    - Varying Terrain Backgrounds

    - Sky Clutter

    - Varying Beam Shapes

    - Side Lobe Detection Regions

    - Side Lobe Clutter

    - Doppler Range Gate Limitations on Clutter

    - Varying Clutter for Different Frequencies

2. A bistatic radar cross section model should be included in the model. The cross section model should be a function of look elevation angle and azimuth angle. The

radar cross section of such a model would provide more insight into subclutter visibility of potential targets.

3. Develop the computer code for mapping of the doppler contours.

```
C     ********************************************************************
C
C                     BISTATIC RADAR PROGRAM
C
C
C     ********************************************************************
1          DIMENSION TABLE(300,250),SPD(10,37),BASE(302),ALT(252),
     C BASE1(38),ALT2(38),I1(30),I2(63),I3(62),Iyy(37),YY(37)
C
C     THE DATA statements set up the plot10 labels
C
           data I1/9,9,9,9,66,73,83,84,65,84,73,67,9,68,69,84,69,
     C67,84,73,79,78,9,82,69,71,73,79,78,83/
           data I2/9,9,9,9,9,83,73,71,78,65,76,9,84,79,9,67,76,85,
     C84,84,69,82,9,82,65,84,73,79,9,40,65,90,73,77,85,84,72,
     c9,65,78,71,76,69,9,86,83,9,69,76,69,86,65,84,73,79,78,
     c9,65,78,71,76,69,41/
           data I3/9,9,9,9,9,68,79,80,80,76,69,82,9,83,80,82,69,65,
     c68,9,79,70,9,66,69,65,77,9,40,65,90,73,77,85,84,72,
     c9,65,78,71,76,69,9,86,83,9,69,76,69,86,65,84,73,79,78,
     c9,65,78,71,76,69,41 /
2          REAL ISOR,ISOMIN,ISOMAX,LA,LN,LOSS
3          INTEGER NPRF,PRF
c
C          Initialize the free variables to default values
c
           P=0.01
           GT=10
6          GR=40
7          SNR=6.5
8          RCS=1.75
9          BW=1
10         LOSS=6.5
15         TEMP=300
25         XWAZ=1.5
30         RWAZ=1.5
31         RWEL=6
32         XWEL=6
33         FO=3
34         Z=0
35         VX=600
36         XAZ=0
37         XEL=0
38         VT=600
39         TAZ=0
40         TEL=0
41         TPULSE=5
```

```
42      PRF=25000
43      NPRF=3
44      XALT=9
        RALT=9
45      SEP=200
46      C=3E5
c
C       dummy4 is a parameter that the user sets to allow the program
C       to set itself up for graphics or Crt mode
c       dummy4 = 1  sends plot10 codes to the tektronix terminal
c
50      PRINT*,'ENTER 1 IF YOU ARE ON A GRAPHIC TERMINAL, ANY OTHER
        C NUMBER FOR A CRT'
52      READ*,DUMMY4
        call welcom(dummy4)
        if (dummy4.eq.1) then
c       **********************************************************************
C               set up for plot10 graphs
c       **********************************************************************
53      ALT(252)=125
        ALT(2)=-125
        BASE(1)=301
        ALT(1)=251
        ALT2(1)=37
        BASE1(1)=37
        DO 54 I=2,38
        BASE1(I)=-200+I*10
54      CONTINUE
        DO 55 I=2,302
           BASE(I)=I-52
55      CONTINUE
56      DO 57 I=3,251
           ALT(I)=0
57      CONTINUE
        end if
C       **********************************************************************
C
C          The user selects the option for the program to execute
C
c       **********************************************************************
60      PRINT*,'DO YOU WANT:         1 ISORANGES'
61      print*,'                     2 DOPPLER MAP'
63      PRINT*,'                     3 SIGNAL TO CLUTTER CALCULATIONS'
        print*,'                     4 DOPPLER SPREAD OF BEAM'
64      READ*,DUMMY3
65      IF (DUMMY3.GT.4) THEN
70          CALL ERROR
73          GO TO 64
75      ELSE IF (DUMMY3.LT.1) THEN
80          CALL ERROR
82          GO TO 64
85      END IF
```

```
200     if (dummy4.eq.1) then
            call wipe
        end if
C**********************************************************************
C
C    The program prints out the current parameter values befor any
C    execution.  This allows the operator to change any value or
C    set of values.
C
C    **********************************************************************
201     PRINT*,'CURRENT VALUES ARE DEFINED AS:'
202     PRINT*,'                    TARGET                TRANSMITTER
        C                RECEIVER'
208     PRINT 1110,VT,VX,TEMP
210     PRINT 1112,TAZ,XAZ,SNR
214     PRINT 1114,TEL,XEL
216     PRINT 1116,RCS,P,LOSS
220     PRINT 1120,Z,XALT,SEP
230     PRINT 1130,GT,GR
240     PRINT 1140,FO,BW
245     PRINT 1150,XWAZ,RWAZ
247     PRINT 1118,XWEL,RWEL
249     PRINT 1119,PRF,RALT
        PRINT 1121,TPULSE
        PRINT 1122,NPRF
250     PRINT*,'ENTER OPTION NUMBER [1-26] TO CHANGE VALUE'
260     PRINT*,'OR 27 TO CONTINUE'
270     PRINT*,'OR 28 TO ABORT'
C **********************************************************************
C
C    Dummy directs the program to an execute mode, a change parameter
C    mode or a quit  mode
C
C    **********************************************************************
300     READ*,DUMMY
310     IF (DUMMY .EQ. 28) THEN
320         GO TO 7777
330       ELSE IF (DUMMY .EQ. 27) THEN
340         GO TO 595
350       ELSE IF (DUMMY .GT. 28) THEN
355         CALL ERROR
360         GO TO 250
370       ELSE IF (DUMMY .LT. 1) THEN
380         CALL ERROR
390         GO TO 250
400     END IF
c
c    subroutine call to change parameters
c
500     CALL CHANGE (DUMMY,VT,TAZ,TEL,VX,XAZ,XEL,TPULSE,PRF,NPRF,
        cFO,SEP,Z,XALT,P,GT,GR,SNR,RCS,BW,LOSS,TEMP,RWEL,RWAZ,
        CXWEL,XWAZ,RALT)
```

- 97 -

```
c
c     recycle to print out of cuurent value table
c
505     GO TO 200
C       TEST DUMMY3 TO FIND PROGRAM TO RUN
595     IF (DUMMY4.Eq.1) THEN
        CALL INITT(1200)
        CALL BINITT
        end if
C   ********************************************************************
C
C     vector to program selection based on dummy3
C
C   ********************************************************************
597     go to (600,640,744,744) Dummy3
C
C       subroutine call to calculation power equation limitation
C       value, R4
C
600     CALL RANGE(P,GT,GR,SNR,RCS,FO,LOSS,BW,TEMP,R4)
c
c       subroutine call to determine the time domain limitations
C       of the minimum and maximum isoranges
c
610     CALL MINMAX(TPULSE,C,SEP,NPRF,PRF,ISOMIN,ISOMAX,I,XALT,RALT)
c
c   if not on a 40XX, print values for isomin and isomax on screen
c
611     if (dummy4.ne.1) then
            print 1160,isomax
            print 1161,isomin
            go to 990
        end if
c
c     if on a 40XX, draw the power equation limitation regions
c        ( the Owals of Cassini)
c
612     call check(base,alt)
        call dsplay(base,alt)
        call hlabel(30,i1)
615     CALL POWER(Z,XALT,SEP,R4,BASE,RALT)
c
c       subroutine call to draw the isorange ellipsiods
c
620     CALL ISOR(ISOMIN,ISOMAX,I,SEP,Z,XALT,BASE,RALT)
c
c     a check to see if all the intermediate ellipsiods are drawn
c     if not, the program will recycle through the isor routine
c     until the minimum, maximum and intermediate ellipses have
c     been drawn
c
627     IF (I.NE.0) THEN
```

```
630        GO TO 620
635    END IF
636    go to 990
640    IF (DUMMY4.EQ.1)THEN
            call wipe
       END IF
c
c    subroutine call to calculate the doppler values for the region
c    defined in the model.
c
645    CALL DOPMAP(VX,XEL,XAZ,VT,TEL,TAZ,FO,C,SEP,XALT,
       CZ,TABLE,RALT)
c
c    a subroutine call to print the doppler values for the plane of
c    interest.  if a graphical plot package is added at a later date,
c    it should be added here.
c
646    CALL DOPPLT(TABLE)
647    GO TO 990
C
C    THE SCR ROUTINE.  This routine calculates the SCR for seven look
c    down angles (5,10,15,20,25,30,35).  The scr is a function of the
C    Azimuthal scan angle as well.
C
744    RCSDB=10$LOG10(RCS)
       IF(Z.GE.RALT) THEN
            PRINT$,' MODEL HAS NO CAPABILITY TO FIGURE "SKY" CLUTTER'
            GO TO 990
       END IF
       DO 900 I=1,7
745        RSEL=I$5
            TABLE(I,38)=RSEL
750        DO 800 J=1,37
755            RSAZ=(J-1)$10-180
                Iyy(J)=INT(RSAZ)
c
C    The subroutine call to calculate the doppler spread of the
C      common beam area.
C
775            CALL DOPSD(SEP,Z,XALT,RSAZ,RSEL,RWAZ,RWEL,XWAZ,XWEL,
       C  VX,VT,FO,C,DOPSR,XSEL,XRAZ,PHIEQU,XEL,XAZ,TAZ,TEL,PHI,RALT)
                SPD(I,J)=DOPSR
c
C    subroutine call to calculate the per unit density of the
C    common beam area
C
780            CALL DENT(PHI,PHIEQU,DEN)
c
C    subroutine call to calculate the common beam area
c
785            CALL AREA(SEP,Z,RSEL,RSAZ,RW,XWAZ,RWAZ,C,ACDB,RALT,XALT)
790            TABLE(I,J)=RCSDB-DEN-ACDB
```

```
800        CONTINUE
900      CONTINUE
c
C      This section sets up the plot10 call for drawing the SCR graph
c
901      IF (DUMMY4.Eq.1) THEN
             if (dummy3.eq.3) then
         DO 902 I=1,37
             ALT2(I+1)=table(1,I)
902      CONTINUE
         CALL CHECK(BASE1,ALT2)
         CALL DSPLAY(BASE1,ALT2)
         call hlabel(63,i2)
         do 904 j=2,7
             do 903 i=1,37
                 alt2(I+1)=TABLE(J,i)
903          continue
             call cplot(base1,alt2)
             n=int(j/2)
             call line(n)
904      continue
             go to 990
             end if
         DO 905 I=1,37
         ALT2(I+1)=spd(1,I)
905      CONTINUE
         call hlabel(62,i3)
         CALL LINE(34)
         CALL CHECK(BASE1,ALT2)
         CALL DSPLAY(BASE1,ALT2)
         DO 907 I=2,7
             DO 906 J=1,37
                 ALT2(J+1)=spd(I,J)
906          CONTINUE
             CALL CPLOT(BASE1,ALT2)
907      CONTINUe
             go to 990
         end if
C
C      If not on a 40xx, the program will Print a table of SCR
c      values and doppler values on the CRT screen.
C
910      PRINT*,('                    SIGNAL TO CLUTTER RATIO AND DOPPLER
     C SPREAD')
         PRINT 1162,(Iyy(I),i=1,37,3)
915      DO 955 I=1,7
920      PRINT 1000,(TABLE(I,J),J=1,37,3),TABLE(I,38)
925      PRINT 1001,(SPD(I,J),J=1,37,3)
955      CONTINUE
990      if (dummy4.eq.1) then
             call tinput(y)
             call finitt(0,700)
```

```fortran
      end if
      PRINT*,'DO YOU WISH TO CHANGE PARAMETERS AND TRY AGAIN
C     (ENTER 1)'
995   READ*,DUMMY
996   IF (DUMMY.EQ.1) THEN
997      GO TO 60
998   END IF
1000  FORMAT(' SCR dB '14F5.0)
1001  FORMAT(' SPREAD ',13F5.0)
1110  FORMAT(' 1   VELOCITY  =  ',F7.2,'   6  VELOCITY  =  ',
     CF7.2,'  18      TEMP   =   ',F6.2)
1112  FORMAT(' 2   AZ ANGLE  =  ',F7.2,'   7  AZ ANGLE  =  ',
     CF7.2,'  19       SNR   =   ',F6.2)
1114  FORMAT(' 3   EL ANGLE  =  ',F7.2,'   8  EL ANGLE  =  ',
     CF7.2)
1116  FORMAT(' 4        RCS  =  ',F7.2,'   9      POWER  =  ',
     CF7.4,'  20      LOSS   =  ',F7.2)
1120  FORMAT(' 5   Z PLANE   =  ',F7.2,'  10  ALTITUDE  =  ',
     CF7.2,'  21       SEP   =  ',F7.2)
1130  FORMAT('                               11       GAIN  =  ',
     CF7.2,'   2       GAIN  =   ',F7.2)
1140  FORMAT:                               12    CARRIER  =  ',
     CF7.2,'  23        BW   =  ',F7.2)
1150  FORMAT('                               13    BEAM WD  =  ',
     CF7.2,'  24  BEAM WD   =   ',F7.2)
1118  FORMAT('                               14    BEAM HT  =  ',
     CF7.2,'  25  BEAM HT   =   ',F7.2)
1119  FORMAT('                               15        PRF  =  ',
     CI7,'  26       ALT   =  ',F7.2)
1121  FORMAT('                               16   PULSE WD  =  ',
     CF7.2)
1122  FORMAT('                               17      # PRF  =  ',
     CI7)
1160  format(' Maximum Isorange = ',f6.2)
1161  format(' Minimum Isorange = ',f6.2)
1162  format(' Az    ',13I5,'   El ')
7777  PRINT*,'THANK YOU AND COME AGAIN'
      STOP
      END
C
C    a short routine to send an error message to the operater
C    if an out of bounds parameter is specified.
C
1     SUBROUTINE ERROR
5     PRINT*,'ERROR IN DATA ENTRY, TRY AGAIN'
10    RETURN
15    END
C
C  a short welcome
C
1     SUBROUTINE WELCOM(dummy4)
      PRINT*,' '
```

```
        PRINT*,' '
        PRINT*,'       Welcome to the World of Bistatic Radar'
        PRINT*,' '
        PRINT*,' '
        PRINT*,'The purpose of this program is to assist the study'
        PRINT*,'of Bistatic Radar.  This program allows for varying'
        PRINT*,'parameters to develop isodoppler and isorange maps,'
        print*,'as well as Signal to Clutter Ratio values and the ,'
        print*,'doppler frequency spread of the clutter cell.'
        PRINT*,'The maps can be displayed on a Tektronix 40XX graphics'
        PRINT*,'terminal and/or generated in hardcopy.  The program'
        PRINT*,'will ask you to input data.  Enter the data required:'
        PRINT*,'All distance measures are in Kilometers.  All angles'
        PRINT*,'in Degrees.  All Velocities in Kilometers per Second.'
        PRINT*,' '
        PRINT*,'The Bistatic Radar system modeled by this system always'
        PRINT*,'assumes the receiver and transmitter form the baseline.'
        PRINT*,'All angles are measured with reference to the base line'
        PRINT*,' '
        PRINT*,'          /'
        PRINT*,'         / Angle Theta (positive)'
        PRINT*,'        /'
        PRINT*,'   ********************************************************'
        PRINT*,'Receiver                                      Transmitter'
        PRINT*,' '
        PRINT*,'STRIKE ANY NUMBER AND CARRIAGE RETURN KEY TO CONTINUE'
        READ *,DUMMY
        if (dummy4.eq.1) then
           call wipe
        end if
        PRINT*,' '
        PRINT*,' '
        PRINT*,'Remember:'
        PRINT*,' '
        PRINT*,'The relationship of kilometers to nautical miles is:'
        PRINT*,'1 Nautical Mile = 1.852 Kilometers'
        PRINT*,'The relationship of kilometers to statute miles is:'
        PRINT*,'1 Statute Mile = 1.613 Kilometers'
        PRINT*,'The relationship of meters per second to nautical miles'
        PRINT*,'per hour is: 1 NM/Hr= 0.514 M/SEC'
        PRINT*,'The relationship of meters per second to statute miles'
        PRINT*,'per hour is: 1 M/Hr = 0.448 M/SEC'
        PRINT*,' '
        PRINT*,' '
50      RETURN
55      END
C
C       THIS SUBROUTINE CALCULATES THE DENSITY OF THE CLUTTER CELL
C
1       SUBROUTINE DENT(PHI,PHIEQU,DEN)
5         X=PHI
30      IF (X.GT.90) THEN
```

```
35          DEN=SQRT((X-90)*3.2111)-32
40      ELSE
45          DEN=SQRT((90-X)*10)-32
50      END IF
55      IF(PHIEQU.GT.30) THEN
56          PRINT*,'MODEL ILL DEFINED AT THIS POINT'
            CORR=0
57      ELSE IF(PHIEQU.LT.1.5) THEN
58          CORR=(PHI/180)*(-8)
59      ELSE
            CORR=(PHI/180)*(9.2*LOG10(PHIEQU)-9.2)
        END IF
        DEN = DEN + CORR
60      RETURN
65      END
C
C   THIS SUBROUTINE CALCULATES THE Area of the clutter cell
c   which is dependent upon the beam geometry and the
c   look down and azimuthal angles
c
1       SUBROUTINE AREA(SEP,Z,RSEL,RSAZ,BW,XWAZ,RWAZ,C,ACDB,RALT,XALT)
5       R2=(RALT-Z)/(SIND(RSEL))
10      Y=R2*COSD(RSEL)*SIND(RSAZ)
15      X=R2*COSD(RSEL)*COSD(RSAZ)
20      R1=SQRT((SEP-X)**2+Y**2+(XALT-Z)**2)
22      rwaz1=rwaz*0.0174533
23      xwaz1=xwaz*0.0174533
25      R3=SQRT((SEP-X)**2+(XALT-RALT)**2)
30      SEC2BI=4*R1*R2/(2*R1*R2+R2**2+R1**2-R3**2)
35      TEST = R2*RWAZ1/R1
40      IF(TEST.GE.XWAZ1) THEN
45          AC=R1*XWAZ1*C*SEC2BI/(2*BW)
50      ELSE
55          AC=R2*RWAZ1*C*SEC2BI/(2*BW)
60      END IF
100     ACDB=10*LOG10(AC)
105     RETURN
110     END
C   Compute The Doppler Spread, and the Transmitter
C   Elevation and Azimuth Angles
1       SUBROUTINE DOPSD(SEP,Z,XALT,RSAZ,RSEL,RWAZ,RWEL,XWAZ,XWEL,
        CVX,VT,FO,C,DOPBR,XSEL,XRAZ,PHIEQU,XEL,XAZ,TAZ,TEL,PHI,RALT)
2       DIMENSION GATE(8,4)
5       REAL LA,LN
25      RWEL2=RWEL*0.5
30      RWAZ2=RWAZ*0.5
35      XWAZ2=XWAZ*0.5
40      XWEL2=XWEL*0.5
45      TEMP=(RALT-Z)/TAND(RSEL)
50      X=TEMP*COSD(RSAZ)
55      Y=TEMP*SIND(RSAZ)
60      TEMP2=SQRT(Y**2+(SEP-X)**2)
```

```
65      XSAZ=ATAND(Y/(SEP-X))
C       THE AZIMUTHAL ANGLE IS NOW DETERMINED
66      IF (RSAZ.GT.180) THEN
            RSAZ=360-RSAZ
        END if
67      PHI=ABS(XSAZ)+ABS(RSAZ)
70      XSEL=ATAND((XALT-Z)/TEMP2)
C       THE EQUIVALENT ANGLE CAN NOW BE DETERMINED
72      PHIEQU=(RSEL+XSEL)/2
75      GATE(1,1)=TEMP*COSD(RSAZ-RWAZ2)
80      GATE(2,1)=TEMP*COSD(RSAZ+RWAZ2)
85      GATE(3,1)=(RALT-Z)*COSD(RSAZ)*TAND(RSEL+RWEL2)
90      GATE(4,1)=(RALT-Z)*COSD(RSAZ)*TAND(RSEL-RWEL2)
95      GATE(1,2)=TEMP*SIND(RSAZ-RWAZ2)
100     GATE(2,2)=TEMP*SIND(RSAZ+RWAZ2)
105     GATE(3,2)=(RALT-Z)*SIND(RSAZ)*TAND(RSEL+RWEL2)
110     GATE(4,2)=(RALT-Z)*SIND(RSAZ)*TAND(RSEL-RWEL2)
115     GATE(5,1)=SEP-TEMP2*COSD(XSAZ-XWAZ2)
120     GATE(6,1)=SEP-TEMP2*COSD(XSAZ+XWAZ2)
125     GATE(7,1)=SEP-(XALT-Z)*TAND(XSEL-XWEL2)*COSD(XSAZ)
130     GATE(8,1)=SEP-(XALT-Z)*TAND(XSEL+XWEL2)*COSD(XSAZ)
135     GATE(5,2)=TEMP2*SIND(XSAZ-XWAZ2)
140     GATE(6,2)=TEMP2*SIND(XSAZ+XWAZ2)
145     GATE(7,2)=(XALT-Z)*TAND(XSEL-XWEL2)*SIND(XWAZ2)
150     GATE(8,2)=(XALT-Z)*TAND(XSEL+XWEL2)*SIND(XWAZ2)
155     DO 160 I=1,8
160         GATE(I,3)=(X-GATE(I,1))**2+(Y-GATE(I,2))**2
165     CONTINUE
C
C       NOW THE PROGRAM LOOKS FOR THE SMALLEST FOUR DISTANCES AND
C           PLACES THE COORDINATES IN THE TOP FOUR RUNGS OF GATE
170     DO 230    N=1,7
175         L=N
180         JJ=N+1
185         DO 210 I=JJ,8
190             IF(GATE(L,3).LT.GATE(I,3)) THEN
195                 GO TO 230
200             END IF
205                 L=I
210         CONTINUE
215         T=GATE(L,3)
216         T2=GATE(L,2)
217         T3=GATE(L,1)
220         GATE(L,3)=GATE(N,3)
221         GATE(L,2)=GATE(N,2)
222         GATE(L,1)=GATE(N,1)
225         GATE(N,3)=T
226         GATE(N,2)=T2
227         GATE(N,1)=T3
230     CONTINUE
C       NOW FIND THE DOPPLER OF THE FOUR POINTS
235     VXZ = (VX*SIND(XEL))/3600
```

```
240    VXY = (VX*(COSD(XEL))*SIND(XAZ))/3600
245    VXX = (VX*(COSD(XEL))*COSD(XAZ))/3600
250    VTZ = (VT*SIND(TEL))/3600
255    VTY = (VT*(COSD(TEL))*SIND(TAZ))/3600
260    VTX = (VT*(COSD(TEL))*COSD(TAZ))/3600
265    LA=C/(FO*1E9)
270    DO 295 I=1,4
275       X=GATE(I,1)
276       Y=GATE(I,2)
277         AP = SQRT(X*X + Y*Y + (Z-RALT)*(Z-RALT))
278         BP = SQRT ((SEP-X)*(SEP-X) + Y*Y + (XALT-Z)*(XALT-Z))
279         FD1=((SEP-X)*(VTX-VXX)+Y*(VXY-VTY)+(XALT-Z)*(VTZ-VXZ))
280         FD1= FD1/(BP*LA)
281         LN=C/(FO*1E9+FD1)
282         FD2 =-1*(VTX*X + VTY*Y + VTZ*(Z-RALT)) / (AP*LN)
290         GATE(I,4)=FD1 + FD2
295    CONTINUE
300    FDMAX=MAX(GATE(1,4),GATE(2,4),GATE(3,4),GATE(4,4))
305    FDMIN=MIN(GATE(1,4),GATE(2,4),GATE(3,4),GATE(4,4))
310    DOPSR=ABS(FDMAX-FDMIN)
320    RETURN
330    END
C
C     This routine prints out a table of values on the screen
C     The values are the doppler frequency  of the plane of interest.
C     A doppler map is construcvted by hand drawing the isodoppler
C      contours.
C
1            SUBROUTINE DOPPLT(TABLE)
5      DIMENSION TABLE(300,250),Iy(15)
10     do 30 I=1,11
          Iy(I)=-150+25*i
30     continue
35     Print*,('              Idodoppler Information')
40     Print*,('<X axis><                        Y axis
       C                           >')
45     Print 100,(IY(i),i=1,11)
50     do 70 i=1,300,5
          ii=i-51
55        Print 105,ii,(TABLE(I,J),J=1,11)
70     continue
100    format('              ',11I6)
105    format(I8,11F6.0)
110    RETURN
115    END
C
C     The routine for interactively changing the variables of interest.
C
1      SUBROUTINE CHANGE(DUMMY,VT,TAZ,TEL,VX,XAZ,XEL,TPULSE,PRF,NPRF,
       cFO,SEP,Z,XALT,P,GT,GR,SNR,RCS,BW,LOSS,TEMP,RWEL,RWAZ,XWEL,
       CXWAZ,RALT)
       INTEGER PRF,NPRF,D
```

```
          REAL LOSS
11        D=INT(DUMMY)
22         GO TO(600,700,800,1600,500,100,200,300,1400,900,1500,1300,
          C 2500,2400,1000,1200,1100,2100,1800,2000,400,1700,1900,2300,
          C 2200,2600)   D
100       PRINT*,'INPUT TRANSMITTER VELOCITY (0-1200)'
140       READ*,VX
150       IF (VX .LT. 0) THEN
155           CALL ERROR
160           GO TO 100
170       ELSE IF (VX .GT. 1200) THEN
175           CALL ERROR
177          GO TO 100
180       END IF
190       GO TO 2700
200       PRINT*,'INPUT TRANSMITTER AZIMUTH ANGLE (0-360 DEGREES)'
240       READ*,XAZ
250       IF (XAZ .LT. 0) THEN
255           CALL ERROR
260           GO TO 200
270       ELSE IF (XAZ .GT. 360) THEN
275           CALL ERROR
277          GO TO 200
280       END IF
290       GO TO 2700
300       PRINT*,'INPUT TRANSMITTER ELEVATION ANGLE (-10 TO +10 DEGREES)'
340       READ*,XEL
350       IF (XEL+10 .LT. 0) THEN
355           CALL ERROR
360           GO TO 300
370       ELSE IF (XEL .GT. 10) THEN
375           CALL ERROR
377          GO TO 300
380       END IF
390       GO TO 2700
400       PRINT*,'INPUT TRANSMITTER RECEIVER SEPARATION (10-200 KM)'
440       READ*,SEP
450       IF (SEP .LT. 10 ) THEN
455           CALL ERROR
460           GO TO 400
470       ELSE IF (SEP .GT. 200) THEN
475           CALL ERROR
477          GO TO 400
480       END IF
*'.?      GO TO 2700
 `0       PRINT*,'INPUT ALTITUDE PLANE OF INTEREST (0-30 KM)'
540       READ*,Z
550       IF (Z .LT. 0 ) THEN
555           CALL ERROR
560           GO TO 500
570       ELSE IF (Z .GT. 30) THEN
575           CALL ERROR
```

```
577        GO TO 500
580    END IF
590    GO TO 2700
600    PRINT*,'INPUT TARGET VELOCITY (0-2500)'
640    READ*,VT
650    IF (VT .LT. 0) THEN
655        CALL ERROR
660        GO TO 600
670    ELSE IF (VT .GT. 2500) THEN
675        CALL ERROR
677        GO TO 600
680    END IF
695    GO TO 2700
700    PRINT*,'INPUT TARGET AZIMUTH ANGLE (0-360 DEGREES)'
740    READ*,TAZ
750    IF (TAZ .LT. 0) THEN
755        CALL ERROR
760        GO TO 700
770    ELSE IF (TAZ .GT. 360) THEN
775        CALL ERROR
777        GO TO 700
780    END IF
795    GO TO 2700
800    PRINT*,'INPUT TARGET ELEVATION ANGLE (-10 TO +10 DEGREES)'
840    READ*,TEL
850    IF (TEL+10 .LT. 0) THEN
855        CALL ERROR
860        GO TO 800
870    ELSE IF (TEL .GT. 10) THEN
875        CALL ERROR
877        GO TO 800
880    END IF
890    GO TO 2700
900    PRINT*,'INPUT TRANSMITTER ALTITUDE (0.01-30 KM)'
940    READ*,XALT
950    IF (XALT .LT. 0.01 ) THEN
955        CALL ERROR
960        GO TO 900
970    ELSE IF (XALT .GT. 30) THEN
975        CALL ERROR
977        GO TO 900
980    END IF
990    GO TO 2700
1000   PRINT*,'INPUT PULSE REPETITION FREQUENCY (1-50000)'
1040   READ*,PRF
1050   IF (PRF .LT. 1) THEN
1055       CALL ERROR
1060       GO TO 1000
1070   ELSE IF (PRF .GT. 50000) THEN
1075       CALL ERROR
1077       GO TO 1000
1080   END IF
```

```
1090    GO TO 2700
1100    PRINT*,'INPUT NUMBER OF PRF FREQUENCYS (1-10)'
1140    READ*,NPRF
1150    IF (NPRF .LT. 1) THEN
1155        CALL ERROR
1160        GO TO 1100
1170    ELSE IF (NPRF .GT. 10) THEN
1175        CALL ERROR
1177        GO TO 1100
1180    END IF
1190    GO TO 2700
1200    PRINT*,'INPUT PULSE WIDTH (0.1 TO 30 MICROSECONDS)'
1240    READ*,TPULSE
1250    IF (TPULSE .LT. 0.1) THEN
1255        CALL ERROR
1260        GO TO 1200
1270    ELSE IF (TPULSE .GT. 30) THEN
1275        CALL ERROR
1277        GO TO 1200
1280    END IF
1290    GO TO 2700
1300    PRINT*,'INPUT CARRIER FREQUENCY (S BAND  2-4 GHZ)'
1340    READ*,FO
1350    IF (FO .LT. 2) THEN
1355        CALL ERROR
1360        GO TO 1300
1370    ELSE IF (FO .GT. 4) THEN
1375        CALL ERROR
1377        GO TO 1300
1380    END IF
1390    GO TO 2700
1400    PRINT*,'INPUT TRANSMITTER POWER (0.00050-2.0 MEGAWATTS)'
1440    READ*,P
1450    IF (P .LT. 0.00050 ) THEN
1455        CALL ERROR
1460        GO TO 1400
1470    ELSE IF (P .GT. 2.0) THEN
1475        CALL ERROR
1477        GO TO 1400
1480    END IF
1490    GO TO 2700
1500    PRINT*,'INPUT TRANSMITTER GAIN (0-45 dB)'
1540    READ*,GT
1550    IF (GT .LT. 0 ) THEN
1555        CALL ERROR
1560        GO TO 1500
1570    ELSE IF (GT .GT. 45) THEN
1575        CALL ERROR
1577        GO TO 1500
1580    END IF
1590    GO TO 2700
1600    PRINT*,'INPUT MINIMUM TARGET CROSS SECTION (0.1-100 Sq M)'
```

```
1640    READ*,RCS
1650    IF (RCS .LT. 0.1) THEN
1655         CALL ERROR
1660         GO TO 1600
1670    ELSE IF (RCS .GT. 100) THEN
1675         CALL ERROR
1677         GO TO 1600
1680    END IF
1695    GO TO 2700
1700    PRINT*,'INPUT RECEIVER ANTENNA GAIN (0-45 dB)'
1740    READ*,GR
1750    IF (GR .LT. 0) THEN
1755         CALL ERROR
1760         GO TO 1700
1770    ELSE IF (GR .GT. 45) THEN
1775         CALL ERROR
1777        GO TO 1700
1780    END IF
1795    GO TO 2700
1800    PRINT*,'INPUT RECEIVER MINIMUM DETECTION SNR  (1-20 dB)'
1840    READ*,SNR
1850    IF (SNR .LT. 1) THEN
1855         CALL ERROR
1860         GO TO 1800
1870    ELSE IF (SNR .GT. 20) THEN
1875         CALL ERROR
1877        GO TO 1800
1880    END IF
1890    GO TO 2700
1900    PRINT*,'INPUT RECEIVER BANDWIDTH (0.5-2.0 MEGAHERTZ)'
1940    READ*,BW
1950    IF (BW .LT. 0.5 ) THEN
1955         CALL ERROR
1960         GO TO 1900
1970    ELSE IF (BW .GT. 2.0) THEN
1975         CALL ERROR
1977        GO TO 1900
1980    END IF
1990     GO TO 2700
2000    PRINT*,'INPUT ESTIMATE OF SYSTEM LOSSES (1-25 dB)'
2040    READ*,LOSS
2050    IF (LOSS .LT. 1) THEN
2055         CALL ERROR
2060         GO TO 2000
2070    ELSE IF (LOSS .GT. 25) THEN
2075         CALL ERROR
2077        GO TO 2000
2080    END IF
2090    GO TO 2700
2100    PRINT*,'INPUT RECEIVER FRONTEND TEMPERATURE (290-500
        CDEGREES K)'
2140    READ*,TEMP
```

```
2150    IF (TEMP .LT. 290) THEN
2155        CALL ERROR
2160        GO TO 2100
2170    ELSE IF (TEMP .GT. 500) THEN
2175        CALL ERROR
2177        GO TO 2100
2180    END IF
2190    GO TO 2700
2200    PRINT$,'INPUT RECEIVER ANTENNA BEAM HEIGHT (1-8 DEG)'
2240     READ$,RWEL
2250     IF (RWEL .LT. 1) THEN
2255        CALL ERROR
2260        GO TO 2200
2270     ELSE IF (RWEL .GT. 8) THEN
2275        CALL ERROR
2277        GO TO 2200
2280     END IF
2295     GO TO 2700
2300    PRINT$,'INPUT RECEIVER ANTENNA BEAM WIDTH (1-5 DEG)'
2340     READ$,RWAZ
2350     IF (RWAZ .LT. 1) THEN
2355        CALL ERROR
2360        GO TO 2300
2370     ELSE IF (RWAZ .GT. 5) THEN
2375        CALL ERROR
2377        GO TO 2300
2380     END IF
2395     GO TO 2700
2400    PRINT$,'INPUT TRANMITTER ANTENNA BEAM HEIGHT (1-8 DEG)'
2440     READ$,XWEL
2450     IF (XWEL .LT. 1) THEN
2455        CALL ERROR
2460        GO TO 2400
2470     ELSE IF (XWEL .GT. 8) THEN
2475        CALL ERROR
2477        GO TO 2400
2480     END IF
2495     GO TO 2700
2500    PRINT$,'INPUT TRANMITTER ANTENNA BEAM WIDTH (1-5 DEG)'
2540     READ$,XWAZ
2550     IF (XWAZ .LT. 1) THEN
2555        CALL ERROR
2560        GO TO 2500
2570     ELSE IF (XWAZ .GT. 5) THEN
2575        CALL ERROR
2577        GO TO 2500
2580     END IF
2595     GO TO 2700
2600    PRINT$,'INPUT RECEIVER ALTITUDE (0.01 - 30 KILOMETERS)'
2605    READ$, RALT
2610    IF (RALT.LT.0.01) THEN
2615        CALL ERROR
```

```
2620      GO TO 2600
2625  ELSE IF (RALT.GT.30) THEN
2630      CALL ERROR
2635      GO TO 2600
2640  END IF
2700  RETURN
2210  END
c
c      the routine to calculate the range constant for the power
c   limiting equation region
c
1          SUBROUTINE RANGE(P,GT,GR,SNR,RCS,FO,LOSS,BW,TEMP,RANGE4)
10     REAL C2,LOSS,TEMP,GT,GR,P,RCS,FO,BW,RANGE4
15     C2=(GR+GT-LOSS-SNR)/10
20     C2=10**C2
25     C3=3.2865E6
30     RANGE4=P*RCS*C2*C3/(BW*TEMP*FO*FO)
35     RETURN
40     END
c
c      The routine to cacluation the doppler frequencies for the plane
c       of interest
c
1      SUBROUTINE DOFMAP(VX,XEL,XAZ,VT,TEL,TAZ,FO,C,SEP,XALT,
       CZ,TABLE,RALT)
5      DIMENSION TABLE(300,250)
10     REAL LA,LN
600    VXZ = VX*SIND(XEL)/3600
605    VXY = VX*COSD(XEL)*SIND(XAZ)/3600
610    VXX = VX*COSD(XEL)*COSD(XAZ)/3600
615    VTZ = VT*SIND(TEL)/3600
620    VTY = VT*COSD(TEL)*SIND(TAZ)/3600
625    VTX = VT*COSD(TEL)*COSD(TAZ)/3600
630    LA=C/(FO*1E9)
635    DO 710 I=1,300,5
640       X=I-51
645      DO 705 J=1,11
650        Y=-150+j*25
655        AP = SQRT(X*X + Y*Y + (Z-RALT)*(Z-RALT))
660        BP = SQRT ((SEP-X)*(SEP-X) + Y*Y + (XALT-Z)*(XALT-Z))
674        FD1=((SEP-X)*(VTX-VXX)+Y*(VXY-VTY)+(XALT-Z)*(VXZ-VXZ))
675        FD1=FD1/(BP*LA)
677        LN=C/(FO*1E9+FD1)
680        FD2 =-1* (VTX*X + VTY*Y + VTZ*(Z-RALT)) / (AP*LN)
700        TABLE(I,J)=FD1 + FD2
705      CONTINUE
710    CONTINUE
735    RETURN
740    END
c
c      The routine that calculates the minimum and maximum values
c      for the  isorange ellipses
```

- 105 -

```
c
1        SUBROUTINE MINMAX(TPULSE,C,SEP,NPRF,PRF,ISOMIN,ISOMAX,I,
C        XALT,RALT)
5        REAL ISOMIN,ISOMAX
7        integer PRF
8        R3 = SQRT(SEP*SEP + (XALT-RALT)**2)
10       ISOMIN=2*TPULSE*1E-6*C+R3
15       ISOMAX=(NPRF*C/PRF)+R3-(TPULSE*1E-6*C)
20       I=INT((ISOMAX-ISOMIN)/10)+2
25       RETURN
30       END
c
C        This routine plots the ovals of Cassini
c
1        SUBROUTINE POWER(Z,XALT,SEP,R4,BASE,RALT)
5        DIMENSION UPPER(302),DOWNER(302),BASE(302)
6        UPPER(1)=301
7        DOWNER(1)=301
11       C4=SEP*(-2)
         DO 135 I=-50,250
             X=I
31           C1=(Z-RALT)**2
72           C2=(Z-XALT)**2
73           C3=C2+C1+SEP**2
741          C5=C4*C1
742          C6=C1*SEP**2+C1*C2-R4
122              B4=X**2+C3/2-X*SEP
123              CC=X**4+C4*X**3+C3*X**2+C5*X+C6
                 B5=B4**2-CC
                 IF(CC.GT.0) THEN
                     UPPER(I+52)=0
                     GO TO 130
                 end if
124                  UPPER(I+52)=SQRT(-B4+SQRT(B5))
130              DOWNER(I+52)=-UPPER(I+52)
135      CONTINUE
232       CALL CPLOT(BASE,UPPER)
233       CALL CPLOT(BASE,DOWNER)
235       RETURN
240       END
c
c   This routine plots the  isorange ellipsiods and keeps track
c    of whether or not the last required ellipsiod has been drawn
c
1        SUBROUTINE ISOR(ISOMIN,ISOMAX,I,SEP,Z,XALT,BASE,RALT)
5        DIMENSION UPPER(302),DOWNER(302),BASE(302)
6        REAL ISOMIN,ISOMAX
7        UPPER(1)=301
8        DOWNER(1)=301
10       SEP2=SEP/2
         GO TO(100,200,300,300,300,300,300,300,300,300,300,300,
        C300,300,300,300,300,300,300,300,300,300,300,300,300,
```

```
        C300,300,300,300,300,300,300) I
100     CURVE=ISOMIN
        GO TO 400
200     CURVE=ISOMAX
        GO TO 400
300     CURVE=10*(I-2+INT(ISOMIN/10))
400     I=I-1
20      A=CURVE/2
23      A2=A*A
        B2=A2-SEP2*SEP2
        C12=B2/A2
24      sTHETA=(XALT-RALT)/SEP
25      CTHETA=COS(ASIN(THETA))
26      C1C=Z*CTHETA-RALT*CTHETA
27      C11=Z*STHETA-RALT*STHEtA+SEP/2
45      DO 65  J=-50,250
46         X=J
50         Y=(B2-(X*STHETA+C10)**2-C12*(X*CTHETA-C11)**2)
           if (y.lt.0) then
               upper(j+52)=0
               go to 55
           end if
           upper(j+52)=sqrt(y)
55         downer(j+52)=-upper(j+52)
65      CONTINUE
66      CALL Line(I+2)
67      CALL CPLOT(BASE,UPPER)
68      CALL CPLOT(BASE,DOWNER)
70      RETURN
75      END
c
c    This routine clears the 40XX screen when in the 40XX mode.
c
1       SUBROUTINE WIPE
5       CALL INITT(1200)
10      CALL BINITT
15      CALL FINITT(0,700)
20      RETURN
25      END
```

Bibliography

1. Bonanno, J., N. Powell, and G. Mallean. "Bistatic SAR Self-Synchronization Concept Development Program," Aeronautical Systems Division, Air Force Systems Command, Contract F33615-82-C-1856 with Westinghouse Defense and Electronic Systems Center. Wright-Patterson AFB OH, April 1983.

2. "ESM Augmented Active Surveillance Evaluation," Vol II. Electronic Systems Division, Air Force Systems Command. Contract F30602-82-C-0084 with Westinghouse Defense and Electronic Systems Center. Rome Air Development Center, Griffiss AFB NY. March 1984.

3. Farina, A. and E. Hanle. "Position Accuracy in Netted Monostatic and Bistatic Radar," IEEE Transactions on Aerospace and Electronics Systems VOL. AES-19, NO. 4, 513-520 (July 1983).

4. Lorti, D. "Airborne Bistatic Radar Operation With Non-Cooperative Transmitters," Aeronautical Systems Division, Air Force Systems Command. Contract F33657-83-C-0048 with XonTech, Inc. Wright-Patterson AFB OH. March 1983.

5. ----- and C. Moreno. "Bistatic Sea and Terrain Scattering Models," Aeronautical Systems Division, Air Force Systems Command, Contract F33657-83-C-0048 with XonTech, Inc.

6. Medgyesi-Mitschang, L. N. "RCS Prediction Techniques for Dielectrically Coated Bodies. Vol I. Final Technical Report. Ballistic Missile Defense Advanced Technology Center. Contract DASG60-82-C-0014 with McDonnell Douglas Research Labs. Huntsville AL. July 1982.

7. Moreno, C. and D. Lorti. "Tactical Bistatic Radar Demonstration (TBIRD) Program," Aeronautical Systems Division, Air Force Systems Command. Contract F33615-79-C-1745 with XonTech, Inc. Wright-Patterson AFB OH. February 1982.

8. Papa, Robert J., K. V. N. Rao, John F. Lennon and James W. Coffey. "A Survey of Terrain Scattering Theory and Measurements for Air Force Systems," Electronic Systems Division, Air Force Systems Command. In-House Report RADC-TR-84-78. Rome Air Development Center, Griffiss AFB NY, April 1984.

9. "Passive Multistatic Radar: R&D Activity Summary," Company Report ATC:82:234, ITT-Gilfillan, ITT, Van Nuys CA, November 1982.

10. Peebles, P. "Bistatic Radar Cross Sections of Chaff," Electronic Systems Division, Air Force Systems Command. Contract DAAK21-82-C-0107 with The University of Florida Gainesville Electronic Communication Lab. Rome Air Development Center, Griffiss AFB NY, June 1983.

11. Skolnik, M. Introduction to Radar Systems. New York: McGraw-Hill Book Company, 1980.

12. -----. Radar Handbook. New York: McGraw-Hill Book Company, 1970.

13. Spiegel, M. R. Mathematical Handbook of Formulas and Tables. New York: McGraw-Hill Book Company, 1968.

14. Stimson, George W. Introduction to Airborne Radar. El Segundo: Hughes Aircraft Company, 1983.

15. Weiner, M. "Multistatic Radar Phenomenology, VOL-I Terrain and Sea Scatter," Electronic Systems Division, Air Force Systems Command. Contract F19628-80-C-0001 with The MITRE Corporation. Rome Air Development Center, Griffiss AFB NY, September 1980.

16. Wylie, C. R. Advanced Engineering Mathematics. New York: McGraw-Hill Book Company, 1975.

VITA

Captain William P. Thomson was born on 20 July 1948 in Phoenix, Arizona. He completed his first degree (Bachelor of Arts in Economics) while serving an enlistment in the USAF. He was selected for Officer Training School while performing duty in the Republic of Korea. During a tour of duty as a Missile Maintenance Officer, he was nominated to the Air Force Institute of Technology for the Undergraduate Engineer Conversion Program. He graduated from AFIT with a Bachelor of Science in Electrical Engineering in March 1981. He served as the Strategic Air Command Missile Facility Electrical Engineer until reentering the School of Engineering to pursue graduate studies 24 May 1984.

Permanent address: Box 3

Morman Lake, Arizona 85121

AD-A163941

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED		1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE				
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFIT/GE/ENG/85D-49		5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION School of Engineering	6b. OFFICE SYMBOL (If applicable) AFIT/ENG	7a. NAME OF MONITORING ORGANIZATION		
6c. ADDRESS (City, State and ZIP Code) Air Force Institute of Technology Wright-Patterson AFB, Ohio 45433		7b. ADDRESS (City, State and ZIP Code)		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Rome Air Development Center	8b. OFFICE SYMBOL (If applicable) OCDE	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		

8c. ADDRESS (City, State and ZIP Code) Griffiss AFB, NY 13441-5700	10. SOURCE OF FUNDING NOS.			
	PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
11. TITLE (Include Security Classification) See Box 19				

12. PERSONAL AUTHOR(S)
William P. Thomson, B.S., Capt, USAF

13a. TYPE OF REPORT MS Thesis	13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Yr., Mo., Day) 1985 December	15. PAGE COUNT 123

16. SUPPLEMENTARY NOTATION

17.	COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Bistatic clutter
17	09		Isorange
			Isodoppler

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Title: AIRBORNE BISTATIC RADAR
         LIMITATIONS AND SAMPLE CALCULATIONS

Thesis Chairman: Major Kenneth G. Castor

Approved for public release IAW AFR 190-1.

LYNN E. WOLAVER   16 JAN 86
Dean for Research and Professional Development
Air Force Institute of Technology (AFIT)
Wright-Patterson AFB OH 45433

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION	
UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS ☐	UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL Major Kenneth G. Castor	22b. TELEPHONE NUMBER (Include Area Code) 513-255-5533	22c. OFFICE SYMBOL AFIT/ENG

DD FORM 1473, 83 APR   EDITION OF 1 JAN 73 IS OBSOLETE.   UNCLASSIFIED

This thesis examined the effects of system configuration and transmitted waveform as applied to an airborne bistatic radar. The study concentrates on the limiting effects of the transmitted signal parameters, the signal to clutter ratio, and the doppler spread of the receiver beam.

The analysis was performed by constructing a computer model to graphically display the results of the applicable equations. The equations developed in this study are: The power limited region equation, the isorange equation, the isodoppler equation, and the signal to clutter ratio. These equations and those of ellipsoidal geometry were used to develop the bistatic radar model.